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GEOLOGY OF THE BIRCH CREEK MOLYBDENITE PROSPECT  
BEAVERHEAD COUNTY, MONTANA

by

Gerald F. Willis

B.S., Boise State University, 1976

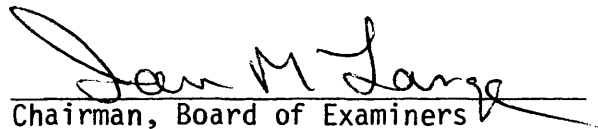
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requirements for the degree of

Master of Science

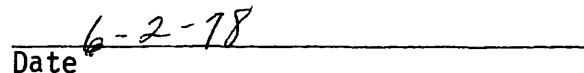
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## ABSTRACT

Willis, Gearld F., M.S., Spring, 1978

Geology

Geology of the Birch Creek Molybdenite Prospect Beaverhead  
County, Montana

Director: Ian Lange

The Birch Creek molybdenite prospect is near the center of the Pioneer batholith of southwestern Montana. Biotite granodiorite is the major rock variety within the mapped area. Lesser amounts of mafic-poor granite also occur. Numerous contorted aplite and pegmatite dikes cut the biotite granodiorite, along with a few northeast trending late basalt dikes. Small quartz-feldspar porphyry masses also cut the granodiorite in the vicinity of Pear Lake. These porphyry masses may be related in space and time to an intrusive breccia pipe located along the western edge of the area, but this is a subject of speculation. Molybdenite with minor chalcopyrite and galena, are sparse, accompanying northeast trending massive quartz veins. These veins follow the northeast structural trend represented by faults, joints, and small fractures. Hydrothermal alteration is confined, for the most part, to narrow envelopes away from the quartz veins. The alteration consists of a phyllic or sericitic zone, in contact with the quartz, which grades outward into a weak intermediate argillic zone and fresh rock. The reasons for sparse molybdenite mineralization is open to speculation. Perhaps a buried intrusion, represented by the intrusive breccia and quartz-feldspar porphyry, controlled mineralization, which has yet to be discovered. It is also possible that there was little molybdenum fractionated in the magma source, resulting in weak molybdenite mineralization.

## ACKNOWLEDGMENTS

I would like to extend thanks to AMAX Exploration, Inc. of Helena, Montana who provided the problem and monetary support for field work during the summer of 1977. I would especially like to thank Giles Walker and Peter Kun of AMAX who supervised the project and provided many helpful suggestions. I am grateful to the members of my committee, Ian Lange, David Alt, and Evan Denney for suggestions and editing of this thesis.

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## CHAPTER I

### INTRODUCTION

The purpose of this study is to provide a detailed geologic outcrop map of a mineralized 10 square kilometer area in the Pioneer Mountains of southwestern Montana. The map (plate 1), at a scale of 1 cm to 50 m, includes rock types, structure, alteration, and mineralization. The data was used to develop a model of mineralization, alteration, ore genesis, and the economic potential of the Birch Creek prospect.

The molybdenite prospect is in a large cirque at the headwaters of Birch Creek (Fig. 1) north of Tent Mountain and south of Torrey Mountain. The Apex exit from interstate 15, approximately 19 km north of Dillon leads to the deposit. The last 8 km of the road beyond Dinner Station campground requires a 4-wheel drive vehicle. The area is accessible only during the summer months.

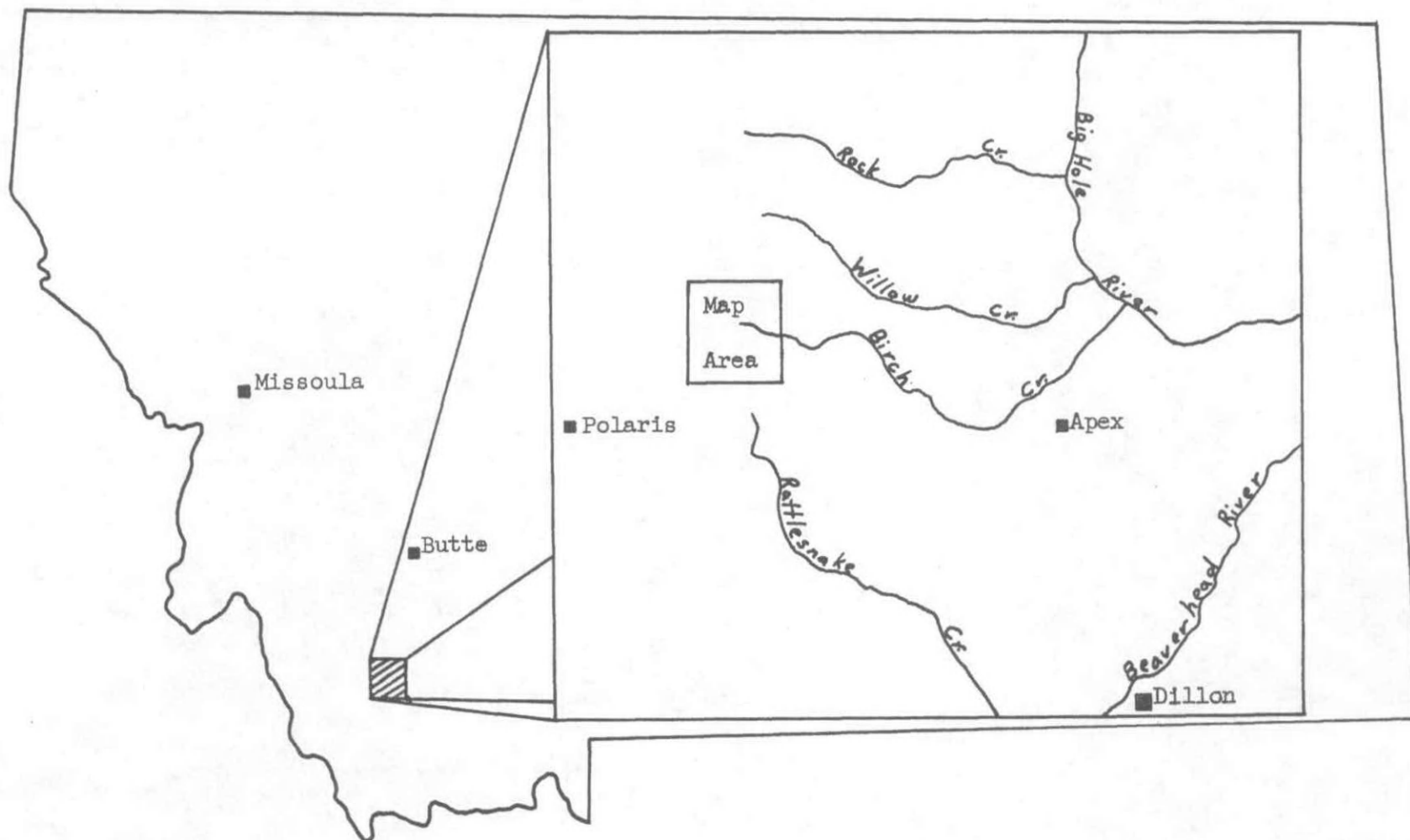


Figure 1 - Generalized location map of study area.

## CHAPTER II

### PHYSIOGRAPHY AND PRESENT TOPOGRAPHY

High rugged mountains and glaciated valleys dominate the prospect area. Elevations range from 2316 meters (7720 ft.) in the extreme east, where Birch Creek leaves the area, to 3132 meters (10,440 ft.) at the top of Highboy Mountain, west of Pear Lake. Torrey Mountain, one of the highest in the Pioneer Mountains at 3344 meters, (11,147 ft.) flanks the area to the north.

A series of lakes scattered throughout the prospect form the headwaters of Birch Creek. The lakes are glacial, but were dammed in the early 1900's to increase their capacity for irrigation of farm land below. Pattee (1960) reported annual precipitation, for selected areas in the Torrey Mountain batholith, ranges from 38 to 50 cm (15 to 20 in.). Geach (1972) refers to the mountainous regions as subhumid and reports that nearby lowland areas of Apex and Argenta have 23 and 25 cm (9.13 and 10.03 in.) per year respectively.

According to Alden (1953), the Wisconsin age glacier that filled the Birch Creek valley was 9 miles (14.4 km) long. The glacier headed in the large cirques above the Birch Creek lakes and west of Torrey Mountain. The large terminal moraine of this glacial advance is crossed by the Birch Creek road near where the road branches above the ranger station. Evidence also exists for an earlier glacial stage that extended further down the valley.

Glacial action in the floor of the Birch Creek cirque carved a series of three steps, several hundred meters high, on which Tub, Anchor, Pear, May, and Boot Lakes rest. The majority of the floor below these steps is obscured by undifferentiated glacial drift and morainal deposits.

The arcuate, southwest shore of Chan Lake is formed by the terminus of a large, active rock glacier. Assuming the rock glacier is ice cored, much of the water in Chan Lake is derived from the glacier and is rich in rock flour. Boulders and talus feeding the rock glacier are spalling from the small cirque to the southwest of the lake. Great amounts of talus and protalus occur at the foot of the large barren rock outcrops also.

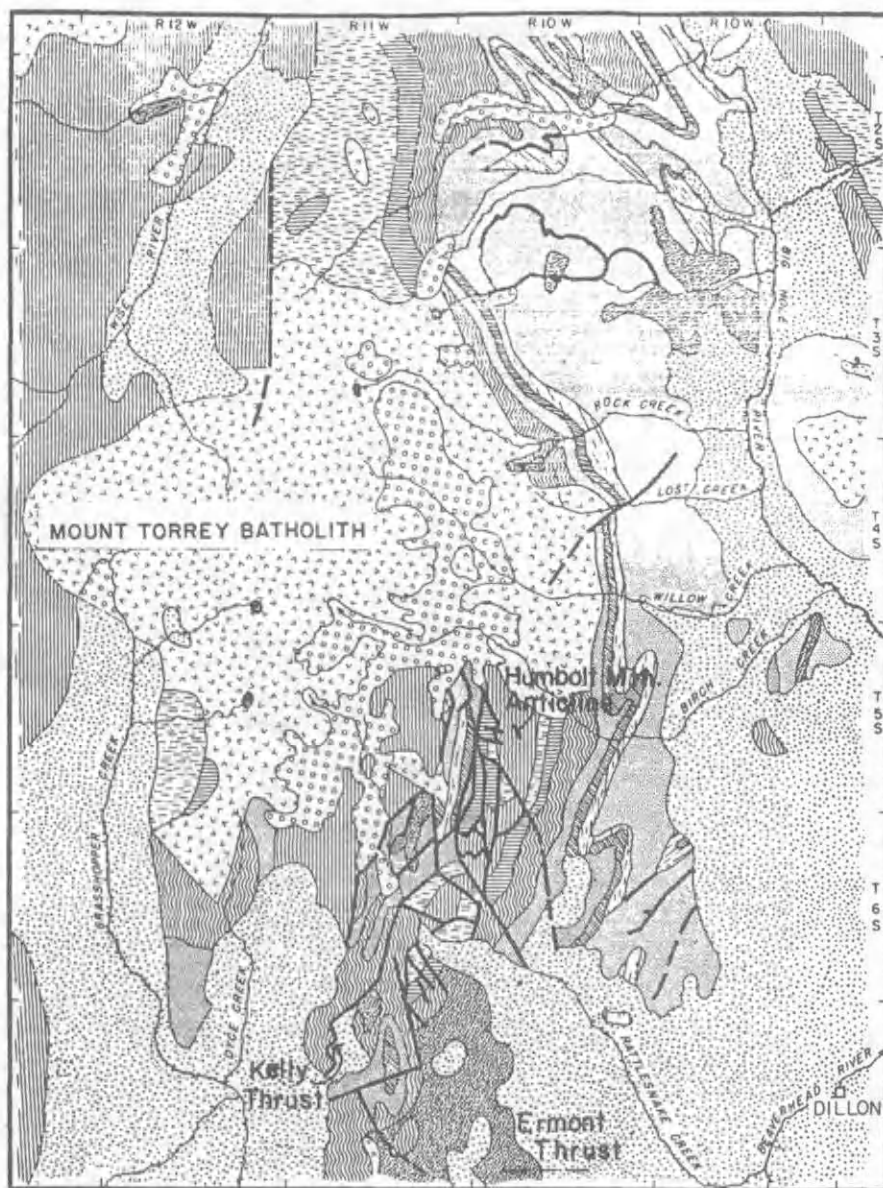
## CHAPTER III

### REGIONAL GEOLOGY

#### General Aspects

Reconnaissance geology of this portion of the Pioneer Mountains and surrounding area was done by Myers (1952), in his study of the northwest quarter of the Willis quadrangle and adjacent Brown's Lake area. Pattee (1960) published a generalized geologic map, adapted from the geologic map of Montana (Ross et al., 1955), showing the Mount Torrey batholith (otherwise known as the Pioneer batholith), in his study of the tungsten deposits related to the batholith (Fig. 2). According to Myers (1952), the region contains sedimentary and metamorphic rocks ranging from Precambrian to Recent, with the interval between upper Cambrian and upper Devonian representing a period of non-deposition. Many of the sedimentary rocks have been contact metamorphosed by the batholith.

The sedimentary rocks to the east and southeast of the batholith have been periodically subjected to extensive folding and faulting, from late Precambrian to mid-Tertiary times. These structures follow a well defined, north to north-northeast trend. Faults dip steeply to the east and folds are overturned to the east. The north-northwest trending Kelley thrust, near Dyce Creek, is the dominant structure
















-  Quaternary glacial drift
-  Cenozoic sediments
-  Tertiary volcanic rocks
-  Tertiary-Cretaceous intrusives
-  Cretaceous sediments
-  Triassic sediments
-  Permian sediments and metamorphics
-  Pennsylvanian sediments and metamorphics
-  Mississippian sediments and metamorphics
-  Devonian sediments
-  Cambrian sediments and metamorphics
-  Precambrian sediments and metamorphics
-  Fault

Figure 2- Geologic map of the "Mount Torrey Batholith" area. (Adapted from the U.S.G.S. geologic map of Montana by Pattee, 1960).

0 2 4 6 mi.  
0 2 4 6 8 km.

in the region and is paralleled by numerous smaller thrusts making up a 3 km wide zone (Fig. 2). The Kelly thrust, which dips to the west, has moved Precambrian quartzites over Paleozoic and Mesozoic rocks. Smaller, steeply dipping normal faults of Tertiary age occur at oblique angles to the thrust faults. Two less dominant, but important, structural features that occur in the area are the Humboldt Mountain anticline between Birch and Rattlesnake Creeks and the Ermont thrust west of Rattlesnake Creek (Fig. 2).

According to Zen and others (1972), five types of intrusive rocks make up the Pioneer batholith. These range from quartz diorite to granite, with the volumetrically most important body being a coarse-grained biotite-hornblende granite (Streckeisen, 1973 IUGS classification). Chemical data for these 5 rock types appears in Table 1. Potassium-argon dates indicate all but the quartz diorite were intruded about 70 m.y. ago. This conflicts with Myers (1952) who believed the intrusion occurred during the interval between the extrusion of the Paleocene and Oligocene volcanic rocks of the area. Other intrusive rocks include sill-like andesite porphyry masses and latite porphyry sills.

Extrusive rocks began accumulating in the late Jurassic, as evidenced by the silicic lava and andesitic pyroclastic rocks in the Morrison formation. Much volcanic debris is observed throughout the post-Kootenai Cretaceous sediments. Altered trachytic tuffs and andesite agglomerate and flows are exposed beneath one of the thrust plates. In addition, rhyolitic and basaltic lavas of Oligocene age occur in the southeastern foothills. None of these extrusive sequences is very extensive.



Table 1. K-Ar Ages, Analytical Data, and Geographic Location  
of Samples from Vipond Park Quadrangle, Montana  
(after Zen and others, 1975)

Rock type, field no.	Location (lat N., long W.)	Analyzed minerals	K <sub>2</sub> O (%)	(moles/g)	Ar <sup>40</sup> * total Ar <sup>40</sup>	Age (m.y.) ± 2
Quartz diorite DR	45°35'36" 112°57'10" Kiokirk Mtn.	Biotite	8.93	9.496 x 10 <sup>-10</sup>	.95	71.0 ± 2.4
			8.87			
		Hornblende	0.887	1.021 x 10 <sup>-10</sup>	0.86	76.5 ± 2.1
Porphyritic granodiorite BH 9850	45°35'18" 112°56'55" Barbour Hill	Biotite	0.887	1.028 x 10 <sup>-10</sup>	0.65	77.0 ± 2.2+
			9.40	9.888 x 10 <sup>-10</sup>	0.90	69.9 ± 2.4
			9.42	9.888 x 10 <sup>-10</sup>		
Coarse granite BHS	45°35'14" 112°56'55" South Barbour Hill	Hornblende	0.915	0.9243 x 10 <sup>-10</sup>	0.81	67.2 ± 1.9
			0.915			
		Biotite	9.30	9.886 x 10 <sup>-10</sup>	0.90	70.6 ± 2.4
Tonalite IVP	45°31'15" 112°50'20" N. Lake Agnes	Biotite	9.32			
			9.12	9.712 x 10 <sup>-10</sup>	0.94	71.0 ± 2.7
			9.08			
Porphyritic granodiorite BC	45°25'0" 112°51'12" Lower Birch Creek	Hornblende	0.627	0.6405 x 10 <sup>-10</sup>	0.80	68.0 ± 1.9
			0.627			
		Biotite	8.77	9.049 x 10 <sup>-10</sup>	0.93	68.8 ± 2.3
			8.73			

### Mining Districts

Several small mining districts are scattered around the edge of the Pioneer batholith and its related intrusives. The ore deposits of the Bannack, Blue Wing, Argenta, Hecla, Utopia, Lost Creek, and the Bald Mountain-Vipond districts (Fig. 3), provided Montana with much of its mineral wealth from the late 1800's to early 1940's. Most mines of the area were closed due to lack of ore and cost of production. Renewed interest was shown in the contact areas around the batholith in the 1950's, with new and old prospects evaluated for their tungsten potential (Pattee, 1960).

Most of the production in the area was from the lead and silver deposits of the Argenta district, with minor gold, zinc, and copper. The Utopia district, on lower Birch Creek, produced a small amount of copper. The majority of the other districts produced some combination of lead, silver, copper, and zinc, along with the later tungsten production (Myers, 1952). These deposits occur as replacement bodies in Paleozoic sediments surrounding the granitic intrusives. No one formation is favored over another, as seen by the fact that ore is found in rocks ranging from the Tilden limestone, to the Three Forks dolomitic shale, to the Flathead quartzite. The geology of these deposits was studied by Winchell (1914), Shenon (1931), Karlstrom (1948), Myers (1952), and Pattee (1960). A Compilation of all ore deposits in Beaverhead County was done by Geach (1972).

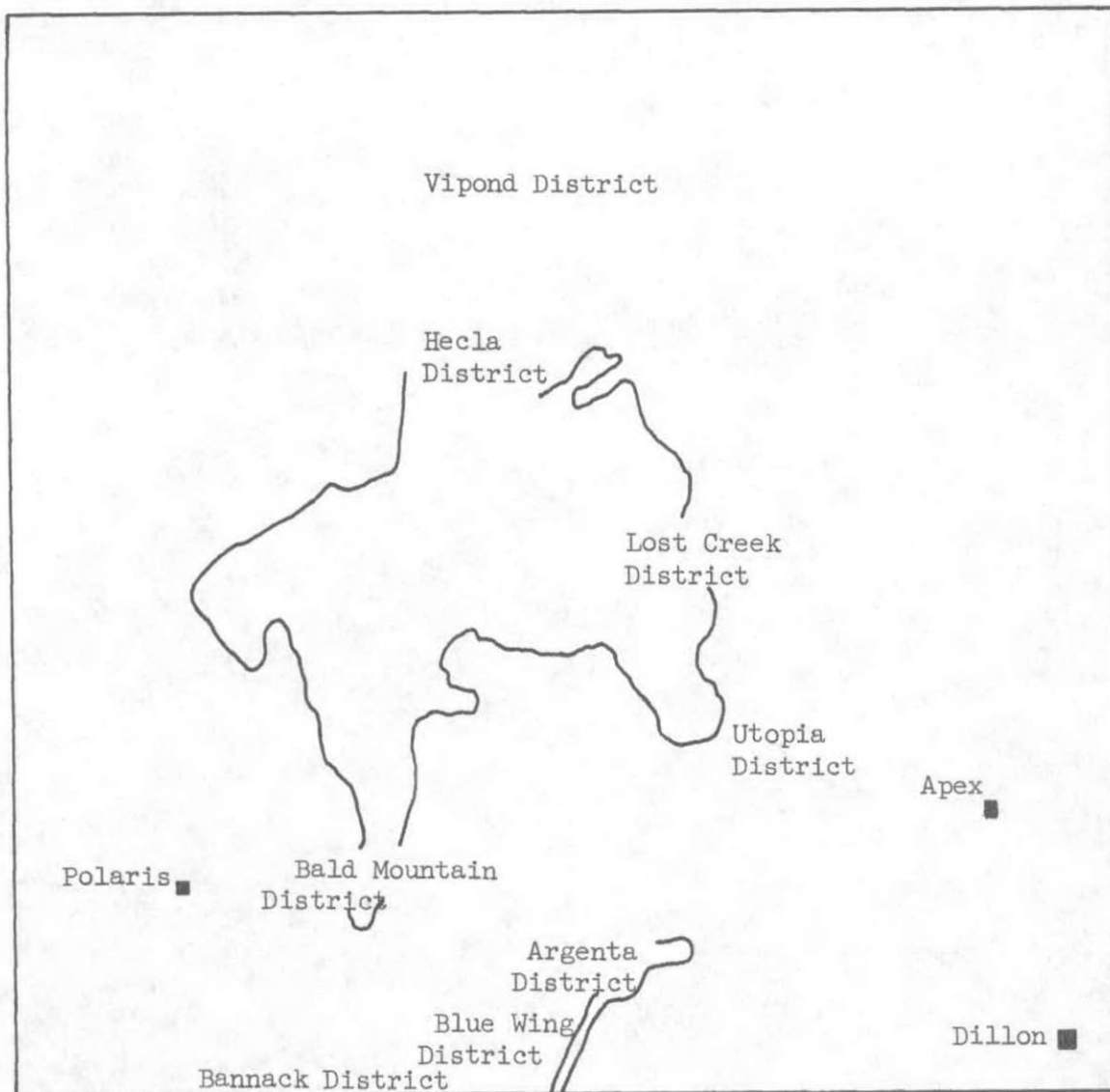
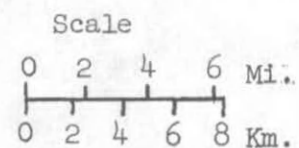


Figure- 3  
Approximate locations  
of various mining  
districts near the  
Pioneer Batholith



Most of the mineralization occurs along structures formed by intrusion of the batholith. Ore bearing fluids, accompanying the intrusions, spread out along the contacts with the surrounding sediments and deposited the minerals in receptive beds and along fractures. No definite mineralogical trend is obvious from one end of the region to the other. The only similarity between the Birch Creek prospect, which lies well within the batholith, and these districts is that the mineralizing fluids may be related to the intrusion of the batholith and its related intrusives. The prospect does lie along the southeast edge of the molybdenum belt proposed by Armstrong and others (1978).

Previous work within the prospect area has not been extensive. Pattee (1960) states that tungsten minerals were reported on the Blackmore prospect, north of Pear Lake, but his investigation of the area revealed no mineralization. In a report on molybdenum deposits in the United States, Kirkemo and others (1965), mention a molybdenite occurrence on the Monaghan prospect, also north of Pear Lake. At one point, one or more persons have attempted to obtain patents on several claims in the area and brass-cap monuments are scattered throughout the area. Assessment work has lapsed on all previous claims rendering them invalid.

CHAPTER IV  
LOCAL GEOLOGY  
Igneous Rocks

Biotite Granodiorite

Biotite granodiorite is the major rock type in the area. This is the biotite quartz monzonite of Myers (1954) and biotite granite of Kirkemo and others (1965). The name biotite granodiorite is in accordance with the IUGS classification of Streckeisen (1973). All other igneous rock types in the area intruded this granodiorite (Plate 2, pocket).

Generally, the rock has a medium-grained granitic texture (Plate 3). Exceptions exist in the northwest corner of the area, where the granodiorite is slightly porphyritic, and on the ridge south of Boot Lake, where it is extremely fine-grained. The exceptions cover only a small area compared to the total mass of the granodiorite and no evidence has been observed to suggest they belong to different intrusions. These deviations grade into the medium-grained, major phase. Numerous football-shaped xenoliths and some flow banding or schlieren occur in the area south of Pear Lake and the ridges on either side of Tent Mountain.

The granodiorite contains abundant subhedral plagioclases, which exhibit both normal and oscillatory zoning as well as carlsbad and albite twinning (Table 2). The plagioclase composition ranges from oligoclase ( $An_{25}$ ) to andesine ( $An_{35}$ ). Euhedral to subhedral hornblende

Table 2. Mineral percentages in major rock types

Minerals	Biotite Granodiorite Oldest	Granite	Aplite dikes	Pegmatite dikes	Quartz-feldspar Porphyry (pheno- crysts) Youngest	Basalt dikes
Quartz	30%	35%	35%	55%	15%	--
Plagioclase	40%	30%	12%	--	30%	75%
K-spar	15%	30%	50%	40%	10%	--
Biotite	10%	2%	1%	5%	5%	--
Hornblende	3%	Tr	Tr	--	1%	
Pyroxene	--	-- <sup>s</sup>	--	--	--	15%
Magnetite	Tr	Tr	1%	--	Tr	2%
Apatite	Tr	Tr	--	--	Tr	Tr
Sphene	Tr	--	Tr	--	Tr	--
Rutile	--	--	--	--	Tr	Tr
Pyrite	Tr	Tr	--	--	--	--
Chlorite	Tr	Tr	--	--	Tr	--
Others (Musc. Limonite, Calcite, Ep.)	1%	2%	1%	--	28% Ground- mass	7%

and biotite, along with rounded quartz are poikilitically included in some grains. The plagioclase is unaltered.

Quartz occurs as anhedral, interstitial grains, between plagioclase, alkali feldspar, and biotite (Table 2). Hornblende and biotite are poikilitically included in the quartz. Myrmekite forms where quartz and plagioclase are in contact. Much of the quartz shows undulose extinction.

Microperthitic orthoclase occurs as large, anhedral grains which poikilitically include all other minerals. The included grains show better crystal form, ranging from euhedral to subhedral, and are smaller than the same minerals in the main body of the rock. According to Hyndman (1972), inclusion of small crystals, like those in the ground-mass, in potassium feldspars is quite common. Such poikilitic inclusions may be the result of late magmatic growth of the feldspar and replacement of surrounding grains (Hyndman, 1968), or normal growth of potassium feldspar in the magma (Hibbard, 1965).

The most striking characteristic of the granodiorite is its biotite content (Table 2), which gives the rock a distinctive salt and pepper appearance. Most grains occur as subhedral to anhedral, ragged, brown flakes. A very small portion of the biotite is a direct result of hornblende alteration. Sphene and subhedral magnetite are arranged preferentially along cleavage in the biotite.

Euhedral to anhedral green hornblende, slightly-oxidized magnetite, and sphene occur as accessories throughout the rock. Sphene occurs

as large individual grains near biotite and is more abundant in the granodiorite than in any of the other rocks examined.

In the porphyritic phase of the granodiorite, the mineralogy is essentially the same. Plagioclase, quartz, and orthoclase all form euhedral phenocrysts. Phenocrysts range from 5 to 10 mm in length and comprise 3 to 5 percent of the rock. Size and composition of the ground-mass is similar to the non-porphyritic phase.

The fine-grained variety has similar mineralogy, with a few exceptions. Microcline, with its distinctive tartan twinning, occurs in place of orthoclase and in smaller amounts. Biotite and plagioclase are more abundant. Chlorite and epidote are present as alteration products of biotite and hornblende. Plagioclase grains clump together in rare instances to form large aggregates. Grain sizes in this phase are nearly half of what they are for each respective mineral in the coarser variety.

The mineralogical composition of the xenoliths within the granodiorite, puts them in the hornblende quartz diorite field (Streckheisen, 1973). Hornblende makes up about 21 percent of the xenolith. Plagioclase ( $An_{25}-An_{28}$ ) is very abundant (62%) as coarse, subhedral grains. Biotite "peppers" the xenoliths and is included poikilitically along with hornblende, within plagioclase. Elongate grains show crude lineation, probably due to alignment during flow within the still plastic mass.

Hornblende and biotite content in the flow bands increases toward the base of the band where they become the dominant minerals in the rock.



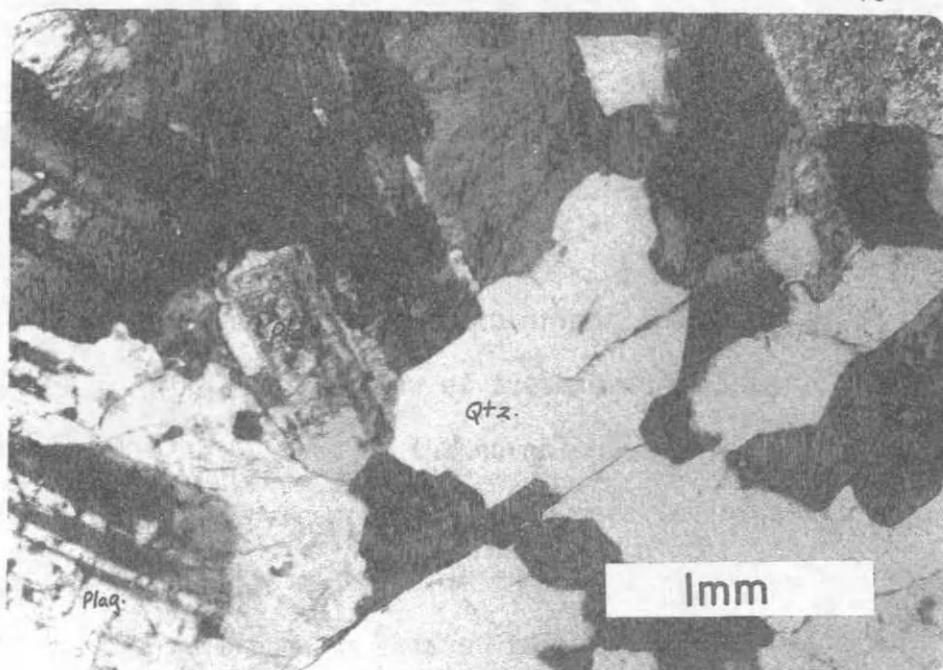


Plate 3-Photomicrograph of biotite granodiorite.

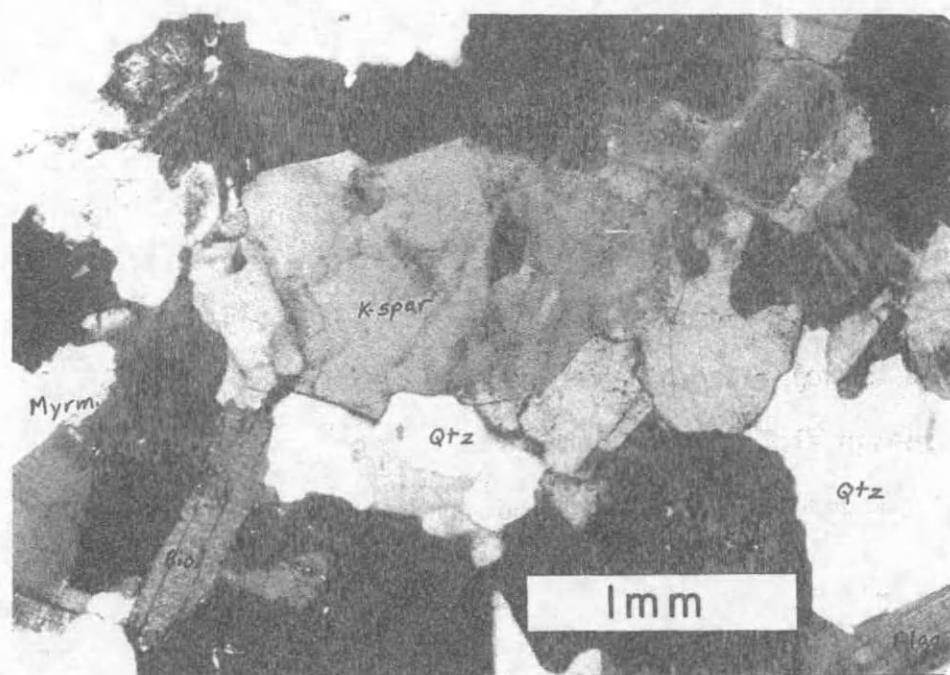


Plate 4-Photomicrograph of granite.

The bands have abrupt contacts at the base and are gradational upward; they resemble the crystal-setting accumulations found in mafic layered intrusions (Fig. 4).

Platy minerals in a magma tend to orient themselves with their largest face parallel to the flow of the magma (Billings, 1972). This explains the parallel nature of the hornblende and biotite in the flow bands. The increased percentage of these parallel minerals is due perhaps, to settling of the mafic minerals as they crystallize. This may be a result of density differences between mafic, and less dense felsic minerals occurring in the upper parts of the bands. As flow continues mafic settling also continues, to the point where they are dominant at the base of the bands. This process would occur assuming an extremely low viscosity in the magma.

South of Pear Lake, a slightly brecciated zone occurs in a fairly large, altered outcrop. Small angular fragments are displaced a few millimeters and a mixture of more mafic minerals and feldspars fill the space between them (Fig. 5). The dark minerals, in particular, show foliation around the fragments. This breccia probably formed as plastic movement ruptured the cooling biotite granodiorite. This agrees with the concept of plastic flow proposed in the formation of broken and offset aplite dikes in the area.

### Granite

A very large, massive granite outcrop occurs to the northwest and adjacent to Boot Lake. A few scattered outcrops also occur to the east,

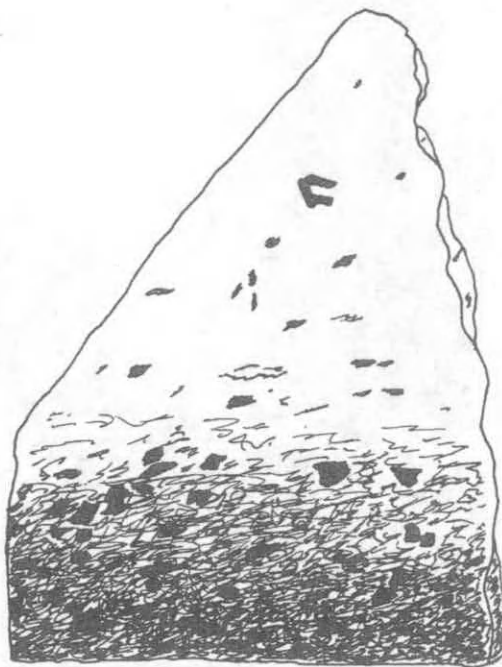


Figure-4- Hand sample showing increased mafic content toward base of the flow band and resemblance to crystal settling

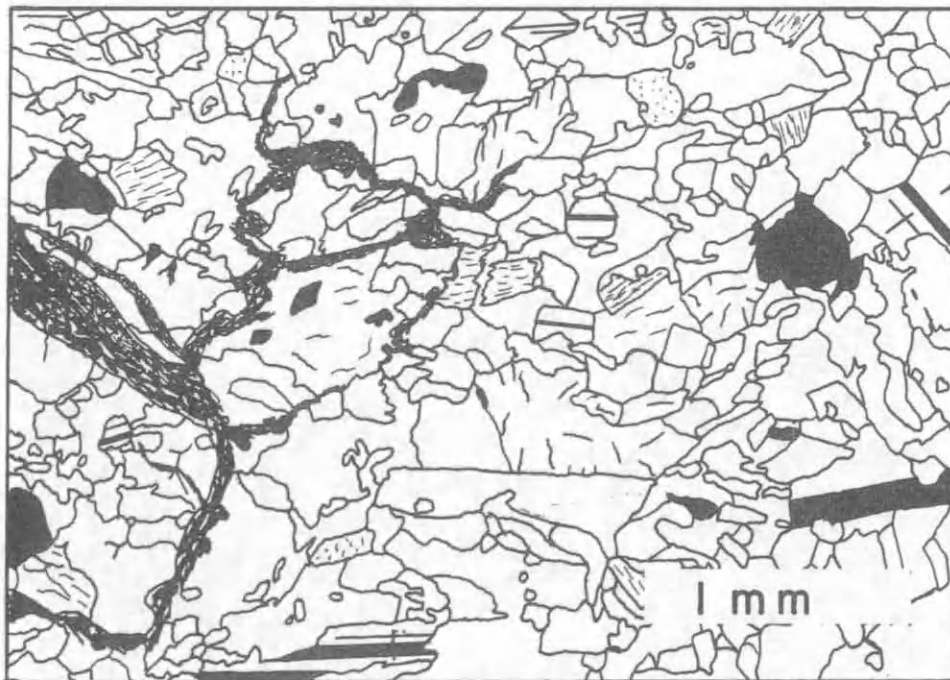


Figure-5- Flow breccia with mafics filling space around fragments.

near the access road which crosses Birch Creek. The granite is poorly jointed and has been rounded and polished by glacial action. Glacial debris covers the biotite granodiorite contact. There is not enough evidence to indicate whether this granite is a phase of the granodiorite or a separate pluton.

The granite is medium to fine-grained and slightly porphyritic (Plate 4). The light color distinguishes it from the biotite granodiorite in outcrop. The rock is composed of quartz, orthoclase, and oligoclase in subequal amounts.

Quartz is rounded and often interstitial between feldspar (Table 2). In some cases it has invaded the feldspar grains. All grains observed show undulose extinction. Grains are .5 to 1 mm in diameter. A few 4 to 7 mm phenocrysts are scattered throughout.

Orthoclase is generally subhedral and slightly perthitic. Many grains are cracked, with fine-grained sericite and clay minerals forming along the open space. These space-filling minerals probably occur as a result of weathering along cracks. Most of the orthoclase in the porphyritic portion of this rock has the same composition.

Many of the subhedral plagioclase grains exhibit normal or oscillatory zoning, as well as carlsbad and albite twinning (Table 2). The plagioclase composition ranges from An<sub>25</sub> to An<sub>28</sub>, well within the oligoclase range. Sericite occurs along grain boundaries and cleavage planes. The sericite is quite coarse-grained and may be secondary muscovite.

Brown biotite makes up about 2 percent of the rock as subhedral intergrowths, interstitial to feldspars and quartz. Magnetite and rutile are poikilitically enclosed along cleavage. Biotite is altering to iron oxides along its borders together with a minor amount of chlorite. Apatite and hornblende are common accessories.

### Aplite Dikes

Aplite dikes are scattered throughout the area, but the majority occur in the lower elevations around Pear and Anchor Lakes. Outside of these areas the aplite dikes occur primarily within the boundary marked for hydrothermally altered, incipient fracturing, as shown in plate 1.

The dikes are usually small, ranging from 1 or 2 cm up to 20 cm in width. In rare cases, dikes are up to a meter in width. These large dikes usually taper to a few centimeters within a meter or two along their length.

A complicating factor in mapping the aplite dikes is their discontinuous nature. The dikes begin and end within a few meters. Many dikes are broken, offset, or bent, which suggests plastic flow of the host rock shortly after consolidation of the dikes or emplacement of the dike material. The regions between broken and offset, but matching pieces, have been filled with biotite granodiorite. In some cases dikes come to an abrupt end with no trace of the matching piece. Despite this, the contacts of the dikes with host rocks are sharp. This irregular nature makes interpretation of regional trends difficult.

The aplite is allotriomorphic-granular or simply aplitic. Grain sizes are variable, but most are 1 mm or less across. Potassium feldspar is the dominant mineral, comprising up to 50 percent of the rock. Quartz, showing undulose extinction, is the next most abundant mineral (Table 2).

Plagioclase composition ranges from  $An_{26}$  to  $An_{29}$ , as determined by flat stage optical methods (X, YAO10). Carlsbad and albite twinning is common. Many grains contain myrmekitic intergrowths of quartz, mainly where in contact with quartz grains. The oligoclase constitutes 11 percent of the aplite dikes.

Hornblende, biotite, muscovite, sphene, and magnetite occur in trace amounts throughout the aplites. Hornblende is subhedral and often pseudomorphically replaced by biotite. Secondary muscovite appears as rather large flakes within feldspars, probably as an alteration product.

#### Pegmatite Dikes

Fewer pegmatite, than aplite, dikes occur in the area. They occur in the higher elevations of the small individual cirques and in the lower regions directly north of Tub Lake. The pegmatitic material commonly outcrops as a coating along an exposed surface or joint.

The dikes are generally quite thin, ranging up to about 7 cm in width. An exception is a large 2 m wide outcrop in the cirque to the northwest of Tub Lake. Most pegmatite dikes have not been subjected to as much plastic deformation as the aplite dikes. Many are bent or

curved though, suggesting a similar process. No trend is observed in the pegmatite dikes either. The pegmatite often grades into aplite on one side or the other.

The pegmatite is composed of large, anhedral masses of milky white quartz grains up to 15 cm across. Large pieces of subhedral to anhedral pink orthoclase are in a 1:1 ratio with quartz (Table 2). The orthoclase breaks along cleavage at times, revealing a slightly perthitic texture. Occasionally, a small amount of coarse grained, subhedral biotite is observed between larger quartz and feldspar grains.

#### Quartz Feldspar Porphyry

Numerous quartz-feldspar porphyry masses crop out in the vicinity of Pear and Tub Lakes. The outcrops have very sinuous, but generally smooth contacts. Occasionally, a few small, angular pieces of wallrock are caught-up in the porphyry. They are never more than a few centimeters from the contact. The inclusions and the wallrock contact show no contact alteration. Many contacts are covered so that not all contact relations can be observed.

The outcrop pattern of the small porphyry intrusions is problematical. Many begin and terminate totally within a single outcrop. Some of the porphyry bodies have a roughly linear shape and resemble dikes, but the majority do not. Flay lying dikes often have an irregular outcrop pattern such as this but a three-dimensional view of these outcrops shows nearly vertical contacts with the enclosing biotite

granodiorite. Intrusion of a crystalline mush during a period of plastic deformation could also account for the sinuous form of the outcrops.

Another possibility is that the quartz-feldspar porphyry intruded in its present form. They may be the upper extensions of a still deeply-buried intrusive, revealed by glacial action. Other factors relating to formation of an intrusive breccia in the area, to be discussed later, may also contribute to a reasonable conclusion.

The quartz-feldspar porphyry is generally quite distinctive in outcrop. On a weathered surface it ranges from light gray to yellowish-brown. The gray rock has a slightly higher quartz content.

This porphyritic texture is a result of two phases of crystallization (Hyndman, 1972). Coarse phenocrysts are formed at a deep level followed by injection to higher levels with a decrease in pressure and development of the fine groundmass.

Phenocrysts constitute between 45 and 65 percent of the porphyry (Table 2). Plagioclase is the most abundant phenocryst, but not the most obvious, comprising 15 to 30 percent of the rock (Plate 5a). It occurs as individual crystals and as aggregates, 1 to 7 mm in length. Phenocrysts are euhedral to subhedral and exhibit oscillatory zoning as well as carlsbad and albite twinning. The composition of the plagioclase ranges from  $An_{15}$  to  $An_{34}$ ; the majority is around  $An_{22}$ . Plagioclase also occurs as tiny microlites in the extremely fine grained groundmass. Individual grains are myrmekitic where in contact with



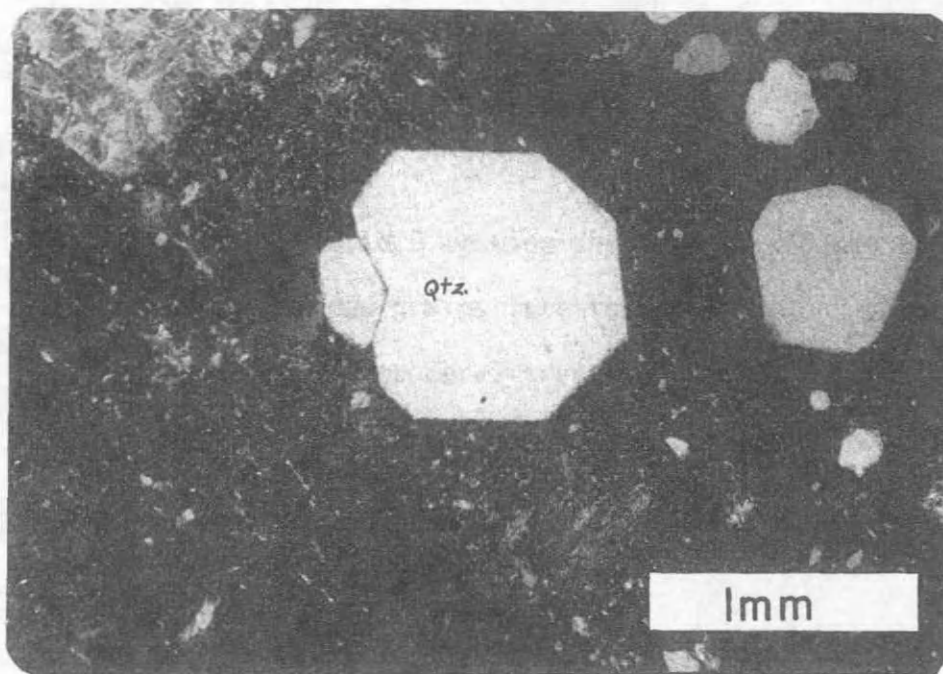


Plate 5a-Photomicrograph of euhedral quartz and plagioclase in quartz-feldspar porphyry.

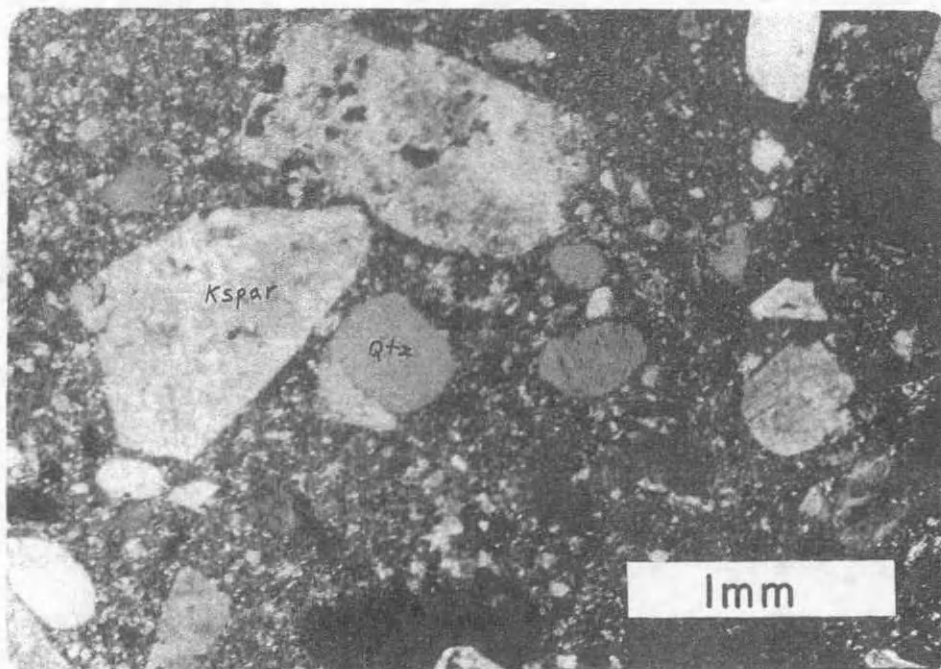


Plate 5b-Photomicrograph of orthoclase and quartz phenocrysts in quartz-feldspar porphyry.

quartz. Phenocrysts are slightly sericitized along crystal boundaries and along cleavage planes.

Quartz is present as 1 to 5 mm wide phenocrysts and aggregates (Plate 5a). The more rounded grains tend to bunch to form large aggregates. Grains range from euhedral crystals, showing little or no strain, to rounded blebs which show undulose extinction. Rounded grains appear cracked and corroded. Moorhouse (1959) suggests that the position of the quartz-feldspar eutectic shifts as a result of changes in temperature and volatile content in the final stages of crystallization, resulting in resolution and corrosion of quartz grains. Corrosion is also suggested as the cause for the roundness of grains. Quartz makes up 15 to 20 percent of the phenocrysts and is also present as microlites in the groundmass.

Giant pink, euhedral to subhedral orthoclase crystals are the most prominent feature of the porphyritic rock (Plate 5b). They range from 2 to 35 mm in length. The primary microperthitic texture gives them a spongy appearance. Grain boundaries are not as sharp in thin section as they appear in handspecimen. Some crystals blend imperceptibly into the groundmass. The larger grains contain numerous poikilitic inclusions of smaller andesine ( $An_{32}$ ), quartz, and biotite. The included plagioclase shows carlsbad and albite twinning. All of these grains have irregular, pitted outlines where in contact with the alkali feldspar. Included biotite, in turn, contains inclusions of magnetite along cleavage. A few of the included grains extend across the

boundary between the large crystal and its matrix. Many of the large crystals are dusted with fine-grained clays.

Smaller accessory minerals are biotite, hornblende, magnetite, apatite, and sphene. Alteration of hornblende to biotite and of biotite to chlorite is common. Rutile needles occur oriented along cleavage in biotite. A sprinkling of sericite occurs in the groundmass. A fairly large percentage of the groundmass is submicroscopic and not identifiable. It probably consists of a mixture of the minerals that make up the phenocrysts.

#### Basalt Dikes

Several large basalt dikes crop out north and northwest of Anchor Lake and on the high ridge directly south of Tub Lake. The reddish-brown dikes have a variable strike, between N50E and N80E and dip steeply to the northwest. The largest dike outcrops discontinuously for approximately 850 m northwest of Anchor Lake. Maximum thickness of any of the dikes is 2.5 m.

All dikes have sharp contacts with the wallrock. There is little, if any, contact effect on the wallrock adjacent to the dikes. Slight shearing and jointing occur parallel to strike. This contributes to the preferential weathering of these dikes, which opens distinct linear throughs cutting through the wallrock. The slightly vesicular nature of the basalt may indicate a shallow depth of emplacement.

The basalt is composed almost entirely of subhedral, feldspar plagioclase laths in a nonoriented mass of pyroxene (Table 2). The plagioclase

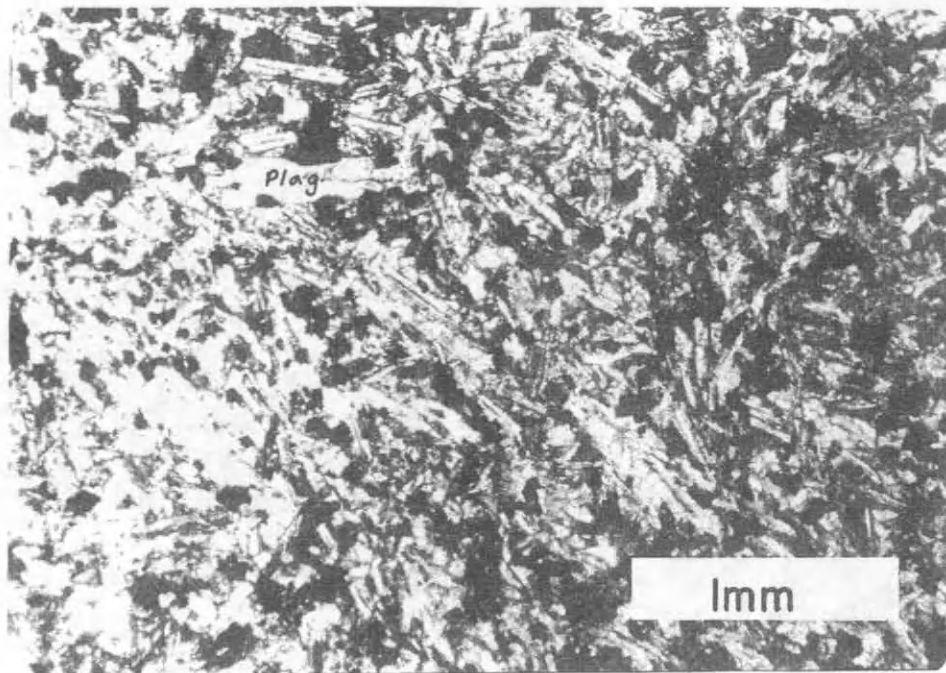


Plate 6-Photomicrograph of basalt dike.

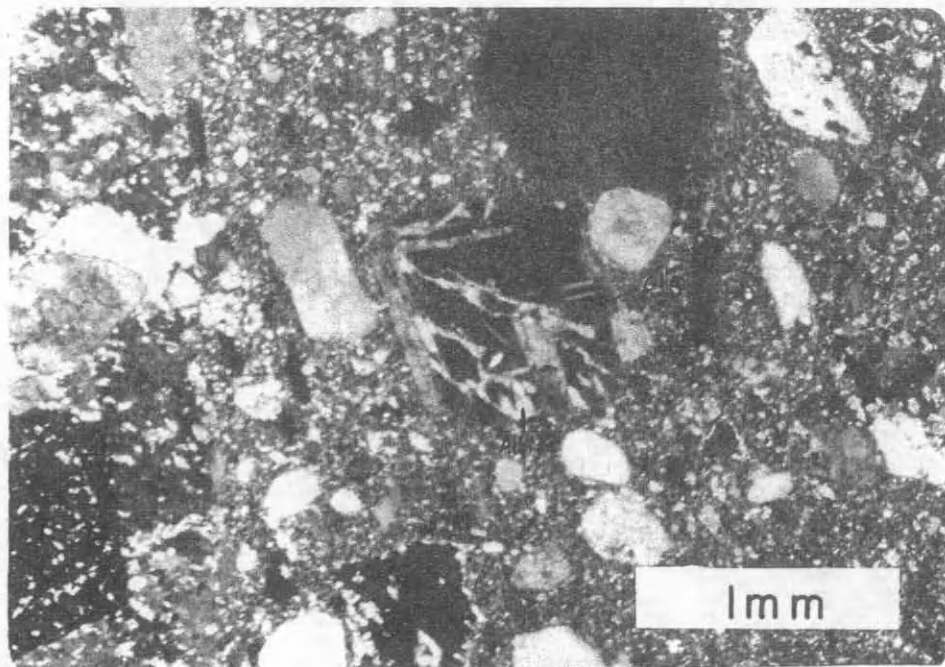


Plate 7a-Photomicrograph of albite in oligoclase grain from intrusive breccia.

is labradorite ( $An_{54}$ ) and constitutes up to 75 percent of the rock (Plate 6). The grains show carlsbad and albite twinning and are not zoned. Much of the plagioclase has been altered, in part, to calcite, fine sericite, and fine clays.

A small percentage of the original fresh augite remains. The remainder has been altered to calcite and reddish-brown iron oxides which are speckled throughout the rock. Alteration of the augite makes positive identification very difficult. Trace amounts of magnetite are scattered throughout the rock.

#### Intrusive Breccia

West of Pear Lake and southwest of Chan Lake is an area of brecciation which resembles the intrusive breccia pipes described by Johnston and Lowell (1961) and Gilmour (1977). A smaller extension of the breccia cuts the granodiorite south of the main body. These intrusive breccia outcrops are on the north and south flanks of Highboy Mountain (Plate 1). The cliff exposure makes it impossible to observe the contact between the breccia and the granodiorite anywhere except along the cliff-talus interface. Contacts in the lower elevations are covered by the rock glacier and talus. All other contacts are inferred. Observable contacts are quite sharp, but may be arbitrary where hydrothermal fluids from the intrusive breccia have caused alteration of the granodiorite. This pipe is probably equivalent to the co-hydrothermal intrusive breccias of Bryner (1961), as opposed to pre-hydrothermal.

The breccia is more resistant to weathering than the jointed rocks around it. It forms a long loaf-shaped outcrop in the lower areas, where the granodiorite has been eroded and covered by talus. According to Gilmour (1977), it is common for intrusive breccia pipes to weather in relief.

The general features of this pipe are essentially the same as those described by Gilmour (1977). The fragments in the breccia pipe consist of the same rocks as the walls. Brecciated biotite granodiorite fragments range from sharp and angular, to well rounded. The fragments are poorly sorted and range in size from rock flour in the matrix to blocks a meter or more across. The maximum dimensions of the majority of the fragments are about 7 cm. A crude flow banding or lineation is evident in isolated localities. The fragments may be very siliceous and/or sericitic, whereas the country rocks are relatively fresh and unaltered.

Johnston and Lowell (1961) describe a well defined mineralogic and petrologic zoning, from an inner core outward into the unaffected wallrock. A similar zoning is evident in this intrusive breccia, but it is not the symmetrical zoning they describe.

There are four recognizable zones moving from west to east along the breccia-talus interface, above the rock glacier. These zones, as shown in Figure 6, are not necessarily all brecciated, but all apparently exist as a direct result of intrusion of the breccia pipe.

Zone 1 is gradational from the unaltered biotite granodiorite

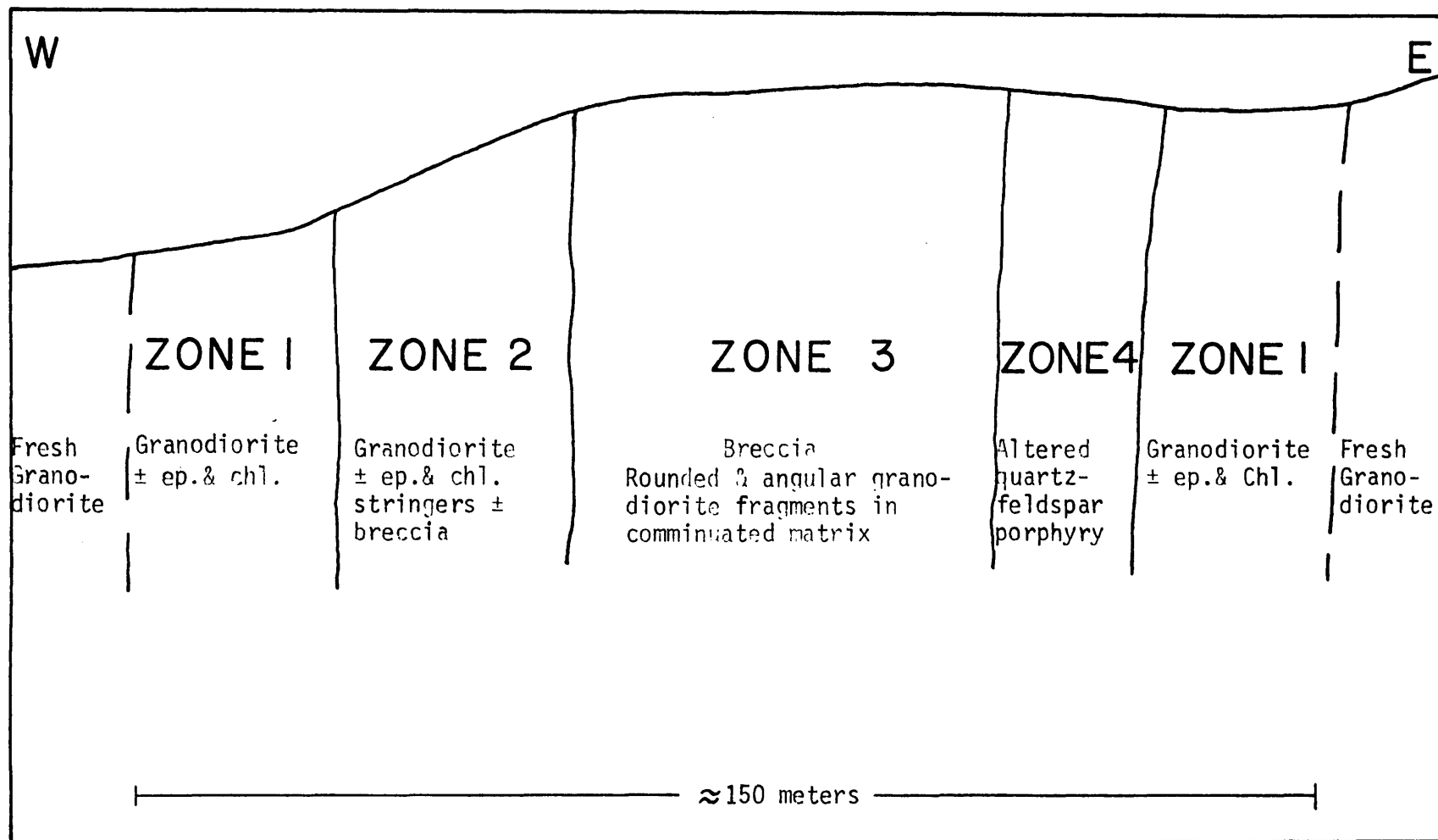


Fig.-6- Idealized diagram of the Birch Creek intrusive breccia sequence. Solid lines-sharp contact  
Dashed lines-gradational contact.

wallrock. The mineralogy is essentially the same as that of the granodiorite. Biotite and hornblende are altered to chlorite and a minor amount of epidote is replacing plagioclase. No fracturing is evident in this area.

Zone 2 represents an abrupt change to granodiorite cut by numerous greenish veinlets of submicroscopic to fine grained quartz, chlorite, epidote, and feldspars respectively. These veinlets also contain phenocrysts of plagioclase and quartz. The biotite granodiorite masses in this zone have been altered quite extensively by fluids that presumably accompanied the intrusive breccia. Quartz grains are corroded, exhibiting a pitted and embayed outline. Many grains have been shattered, offset, and rehealed by a lower relief mineral. This lower relief mineral, as compared to oligoclase ( $An_{28}$ ) it cuts, is apparently albite (Plate 7a). Plagioclase is altered to sericite, epidote, and calcite. Epidote makes up 7 percent of the rock.

Orthoclase has an irregular, dirty appearance and has also been slightly albitized. Chlorite, after biotite, and magnetite are common accessories.

A sharp boundary separates the slightly brecciated rocks of zone 2 and the extremely brecciated rocks of zone 3. A fine-grained greenish-gray matrix makes up the major part of the rock in zone 3. Rounded to angular fragments of biotite granodiorite float within (Plate 7b).

The matrix is comminuted rock of the same composition as the enclosed fragments. The groundmass ranges from submicroscopic to very coarse in size. Anhedral, angular to subangular quartz is the dominant



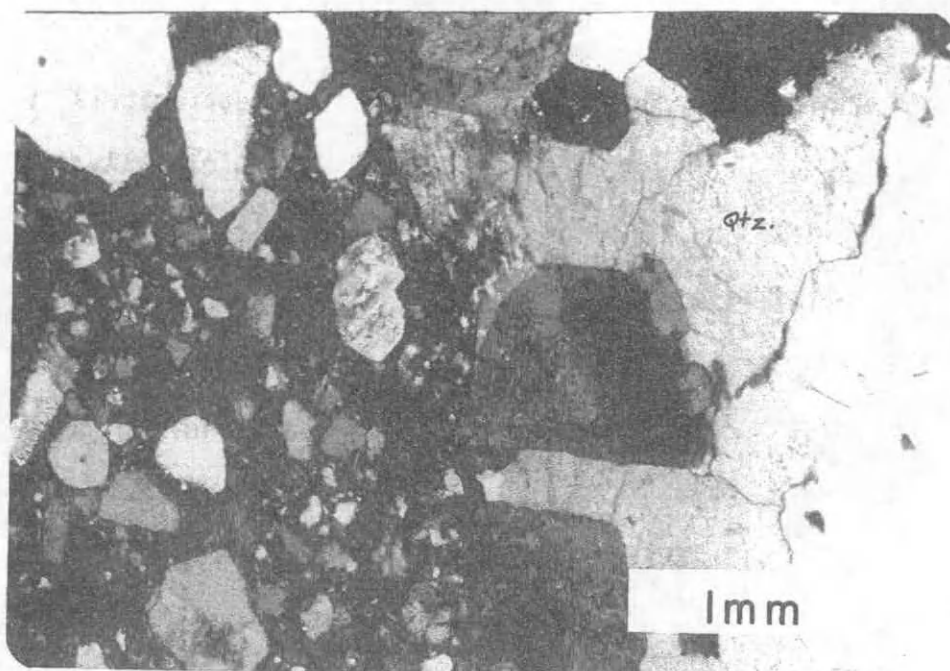


Plate 7b-Contact between brecciated biotite granodiorite on right and groundmass on left.

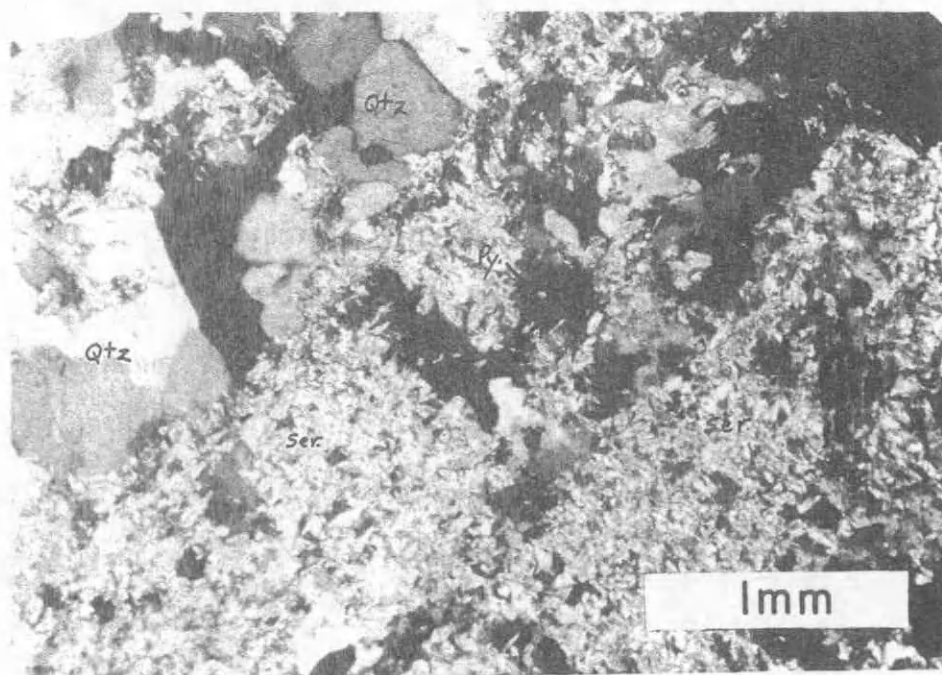


Plate 8-Photomicrograph of phyllic alteration near quartz vein.

mineral. Plagioclase is subhedral to anhedral, well twinned, and ranges from An<sub>29</sub> to An<sub>37</sub>. It shows albite along fractures similar to that in zone 2, but in smaller amounts. Myrmekitic intergrowths envelop entire plagioclase grains. Anhedral, interstitial microcline is present rather than orthoclase. Brown biotite has a ragged outline and is being converted to chlorite on the outer rim. Epidote is replacing plagioclase in trace amounts.

The biotite granodiorite fragments are virtually unaltered. Lack of alteration minerals is the major difference between these fragments and those of zone 2. There is no albite along fractures in these fragments. The contact between the fragments and matrix is always sharp.

Zone 4 is close to the inward edge of the breccia sequence. This zone represents an abrupt change from the brecciated rock to a white chalky rock with quartz phenocrysts and feldspar phenocrysts up to 1.5 cm in length. It appears that this rock is the bleached equivalent of the quartz-feldspar porphyry described earlier. Phenocrysts have not been altered to the same extent as the groundmass. Quartz and plagioclase phenocrysts show the least alteration. Twinning is recognizable in most plagioclase phenocrysts, even where they have been albitized. The bulk of the rock is a fine-grained mixture of quartz, clays, sericite, chlorite, and epidote. Apparently the hot fluids which accompanied the intrusive breccia caused this alteration.

The next zone encountered is very similar to zone 1. Zones 2 and 3 are not repeated as suggested by Johnston and Lowell (1961). This zone is slightly porphyritic and has a great amount of epidote and

chlorite. Gradation into clean biotite granodiorite occurs within a few meters.

The intrusive breccia ends rather abruptly to the southwest of Chan Lake, where it is cut by a small fault. No sense of movement can be detected on the fault. A small amount of unaltered porphyry is found on either side of this fault.

Gilmour (1977) suggests that such breccia pipes may owe their existence to a later, deeper intrusive that is still concealed. According to Gates (1959) and Bryant (1968) the breccia formation is a result of hydrothermal fluids derived from a concealed intrusion. A natural pressure gradient produced by the differences in confining pressure and vapor pressure in the crystallizing magma, caused the hydrothermal fluids to ascend along zones of structural weakness. Biotite granodiorite rock fragments in these weak areas were caught up in the fluid and transported toward the surface. The broken fragments and matrix are deposited when the pressure gradient becomes too weak to move the material or the channelway becomes restricted. Because the breccia is formed by hydrothermal fluids derived from the buried intrusion, no fragments of that intrusion are contained within the breccia. This intrusion is not necessarily violent and probably occurs in a series of pulses (Fig. 7).

Perry (1961) has proposed that breccia pipes such as this, containing rounded fragments, vented to the surface. Upward streaming gases caused tumbling and rounding of the once angular fragments by abrasion and corrosion. Gilmour (1977) adds that a mixture of rounded and angular fragments may be the result of angular wallrock falling

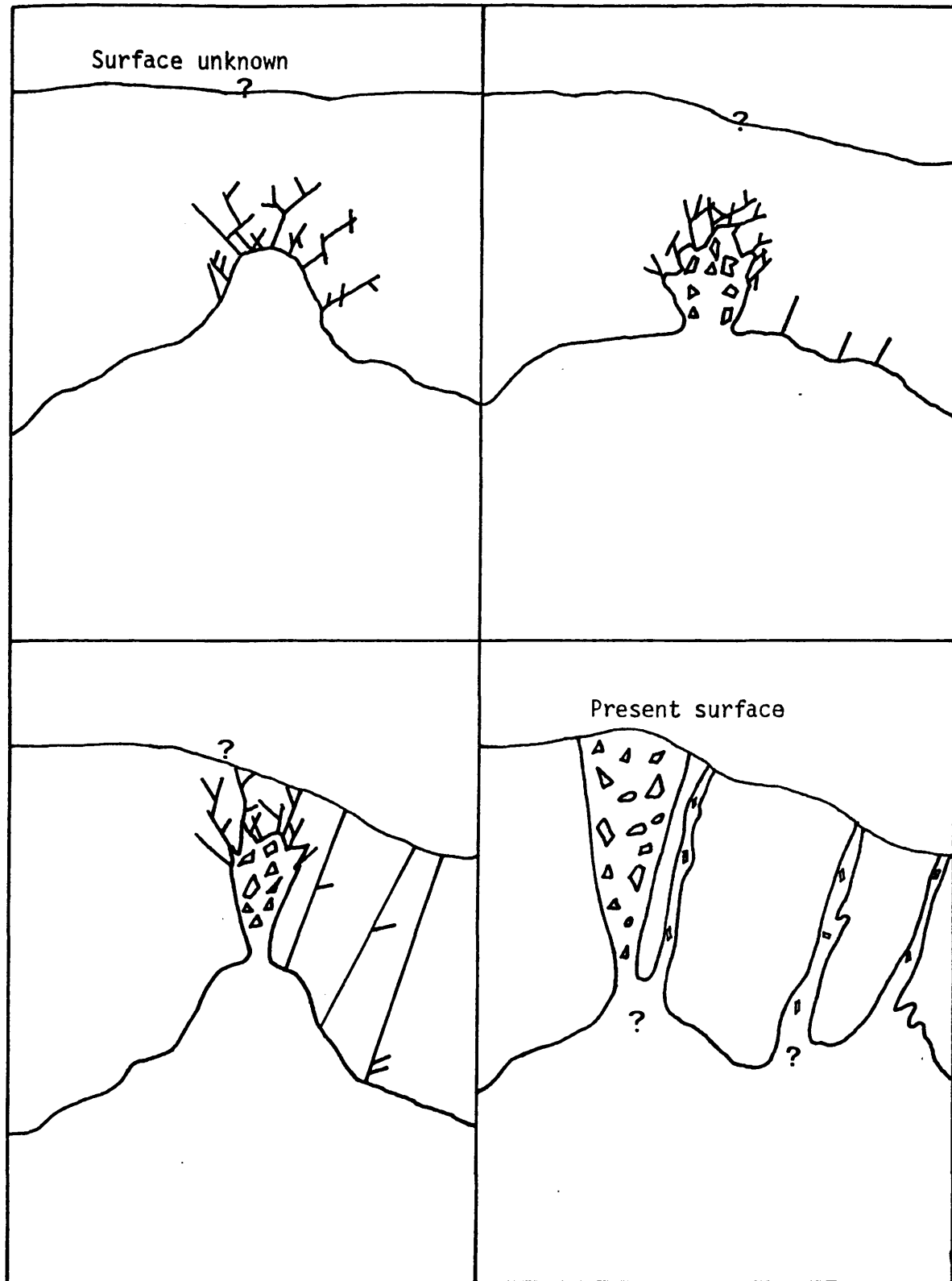


Figure-7- Idealized formation of the Birch Creek intrusive breccia  
(modified after Gates, 1959)

into the already mature pipe, containing rounded fragments. Subsidence of the intrusive breccia after venting may be another source of angular fragments.

If such an intrusive breccia is indicative of a deeper intrusive phase, the irregularly-shaped quartz-feldspar porphyry outcrops may be another expression of that phase. In any event, the breccia pipe is closely related to the porphyry since altered porphyry occurs as part of the breccia sequence and unaltered porphyry is found both on the non-brecciated and brecciated sides of the small fault. It is also possible that this close association is a mere coincidence and the breccia and porphyry are not related.

#### Feldspathic Quartzite

A medium to coarse grained, light colored, feldspathic quartzite is the only non-igneous rock recognized in the area. It occurs in one outcrop to the west of Tub Lake and south of Highboy Mountain. The quartzite is a 2 m by 5 m inclusion in the biotite granodiorite. Its contact with the wallrock is sharp, but irregular. There is minor alteration of biotites to chlorite a few centimeters away from the contact. The outcrop is heavily jointed and no relic bedding is evident.

The rock is about 75 percent quartz, 10 percent plagioclase, together with lesser amounts of orthoclase, sericite, calcite, and chlorite. Microcline, magnetite, and sphene occur in trace amounts. All grains are anhedral. Limonitic coatings are found on many microfractures. The larger elongate mineral grains show a crude lineation.

Myers (1959) has mapped much light colored, feldspathic quartzite of Precambrian age ( $P_{C2}$ ) within 4.5 kilometers of the area. These quartzites are on the upper plate of the Kelly thrust and may be the same as the inclusion. The rocks of this upper plate are probably somewhere within the Precambrian section described by Ruppel (1975; 1976).

### Structure

The area is structurally simple. The most striking features are the wide fault zones south of Highboy Mountain and west of Tub Lake. Two similar zones occur north of Anchor Lake. Each shear zone is preferentially weathered due to the high density of small parallel fractures. These faults trend N50 to 80E, and dip steeply, cutting the biotite granodiorite. Two exceptions to this trend occur along the ridge east of Tent Mountain. These steeply dipping faults trend N20 to 30W. The amount of displacement along these sheared zones is not known.

Evidence of movement can be seen in the fault to the east of Anchor Lake. This steeply dipping fault is well-defined in the northeast where barren outcrop is well-exposed by the stream. The most recent movement resulted in the northeastern or hanging wall being upthrown. Another fault intersects the surface at this point and is shallow dipping. Quartz veins up to 15 cm wide have been emplaced along these faults. There has been movement along the shallow dipping fault since the quartz was emplaced. Fine-grained gouge washed out of this fault was predominantly quartz and hydrothermally altered rock. Adjacent to the fault, on either

side, are a series of small en-echelon quartz veins, approximately paralleling the strike of the faults. It is likely that these quartz veins were emplaced in small tear joints accompanying the faulting.

The entire area is cut by a series of steeply dipping fractures and joints following the same northeast trend as the faults (Fig. 12). No offset is apparent in fractures showing cross-cutting relations. This fracture and joint system dictates the outcrop pattern and topography in the lower elevations, around the lakes. The elongate outcrops are a result of glacial scouring of the less resistant rock along fractures and joints.

These northeasterly trending faults and joints are parallel to subparallel to large fault zones mapped by Myers (1954) about 2 km east of the study area. He believes these larger, more extensive faults to be pre-intrusive in age; accompanying faults may be Oligocene in age.

Another joint set strikes northwest (Fig. 12). It appears to be a later set and is not as prominent as the northeast trending set. These joints follow the same trend as the northwest trending faults near Tent Mountain. They cut the northeast trending joints and show minor offset. Little of the topography is affected by these joints.

Both of these sets of joints cut the sheetlike flow layers observed in the southwest corner of the area, from Tent Mountain to just west of Tub Lake. According to Balk (1937), this type of flow structure is believed to have formed just prior to the final consolidation of the rock.



**WESTERN HALF BIRCH  
CREEK MOLYBDENITE PROSPECT**

Histograms showing strike and percentage of  
joints in 15 degree increments - 100 joints  
per area

Scale  
0 100 300 Meters

Figure 12



The flow banding is indicated by linear parallelism of hornblende laths and linear elongation of xenoliths. Many of the xenoliths have been fractured and cross-cut by aplite dikes.

Balk (1937) suggests that schlieren may be a better term to apply to layers such as these when they are somewhat irregular in shape. Irregular aplitic and ferromagnesian layers are common west of Tub Lake. Length, thickness, and boundaries of these layers vary greatly.

Balk (1937) describes joints, such as the northeast trending set in the study area, that are perpendicular to primary flow bands, as cross or tension joints. These joints are generally long and straight, with veneers of hydrothermal minerals. Tension joints are among the earliest fractures to form with consolidation of the mass.

Flow bands, in this case, represent the trend of greatest lengthening of the igneous mass. The trend of greatest compression lies within the plane of cross joints, normal to the flow lines. These cross joints develop as soon as flow stops and the elastic limit of the rock is exceeded. Expansion, by way of these joints, continues in the same direction as the earlier viscous flow.

The northeast-trending joints and faults in the area have acted as major channelways for hydrothermal fluids. Most of the mineralized quartz veins and hydrothermal alteration is found along these joints and faults. This fact indicates the faults, at least, are quite deep seated or at least penetrated the hydrothermal reservoir.

### Age Relationships

Some of the age relationships between rock types and events have been established through radiometric age dating and others by cross-cutting relationships or inference. Waterhouse (1952) concluded that the Mount Torrey stock (biotite granodiorite of the prospect area) is Tertiary in age. It is not known what this conclusion was based on. However, studies conducted by Zen and others (1975), throughout the Pioneer batholith, indicate the rocks are approximately 70 million years old. This date was derived from potassium-argon (K-Ar) dates on biotite and hornblende in 5 different rock types within the batholith (Tables 1 & 3). The smaller granite body is presumably the same age, but no contact relations with the biotite granodiorite are visible to test this assumption.

Introduction of aplite and pegmatite dikes followed intrusion of the granite and granodiorite (Fig. 8). These dikes were preceded by a joint set in the still plastic granodiorite. The proposed plastic flow occurred during or shortly after the intrusion of the aplites. Emplacement of the flow breccia must have occurred at this time also.

Potassium-argon dates on biotite in the quartz-feldspar porphyry, and coarse grained secondary muscovite in the hydrothermal alteration and quartz-sericite veins gives ages of  $67.9 \pm 2.6$ ,  $67.0 \pm 2.1$ , and  $65.2 \pm 2.4$  respectively (AMAX 1977, personal communication). Considering

Table 3. Data on the Five Dated Intrusive Rocks of the Pioneer Batholith, Montana

(after Zen and others, 1975)

	DR	BH9850	BHS	IVP	BC
Chemical Data					
SiO <sub>2</sub>	52.4	67.7	72.8	65.7	69.5
Al <sub>2</sub> O <sub>3</sub>	18.2	16.4	15.1	16.2	16.2
Fe <sub>2</sub> O <sub>3</sub>	5.1	2.1	0.86	2.8	1.6
FeO	5.4	2.9	0.76	2.1	1.3
MgO	3.9	1.8	0.43	1.5	0.62
CaO	8.7	4.2	2.2	4.5	3.7
Na <sub>2</sub> O	3.0	3.3	3.1	3.0	3.8
K <sub>2</sub> O	1.3	2.8	3.5	2.6	2.7
K <sub>2</sub> O <sup>+</sup>	1.0	0.75	0.96	0.80	0.79
H <sub>2</sub> O <sup>-</sup>	0.07	0.04	0.14	0.12	0.15
TiO <sub>2</sub>	1.2	0.59	0.20	0.42	0.26
P <sub>2</sub> O <sub>5</sub>	0.35	0.14	0.18	0.21	0.16
MnO	0.11	0.10	0.08	0.08	0.08
CO <sub>2</sub>	0.02	0.05	0.02	0.02	0.04
Total	101	100	100	100	101
Modal Minerals					
Quartz	4.3	22.8	34.1	26.0	28.5
Plagioclase	64.9	29.9	31.5	51.0	47.1
K-feldspar	0.0	17.9	29.0	4.3	17.3
Hornblende	17.2	2.3	0.0	4.3	0.3
Biotite	7.7	15.4	4.3	7.8	4.5
Chlorite	0.0	0.0	0.3	1.2	0.9
Sphene	0.4	0.6	0.0	0.8	0.3
Others*	5.6	1.4	0.8	4.7	1.1
Name <sup>+</sup>	Quartz diorite	Granodiorite	Granite	Tonalite	Granodiorite

Table 3. (Continued)

Normative Minerals					
Q	6.5	22.3	36.3	26.6	28.2
Qr	7.6	16.6	20.6	15.4	15.8
Ab	25.2	28.0	26.2	25.4	31.9
An	32.1	20.0	9.6	20.8	16.9
Wo	3.5	0.0	0.0	0.0	0.0
En	9.6	4.5	1.1	3.7	1.5
Fs	3.9	2.8	0.50	1.0	0.80
Mt	7.3	3.1	1.2	4.1	2.3
Il	2.3	1.1	0.38	0.8	0.49
Ap	0.82	0.33	0.43	0.5	0.38
Cc	0.045	0.0	0.045	0.46	0.09
C	0.0	0.64	2.7	0.82	0.77
Thornton and Tuttle differentiation index	39	67	83	67	76

\*Indicates orthite, opaques, epidote-clinozoisite, apatite, zircon, white mica, myrmekite.

<sup>+</sup>Names according to IUGS system (Streckeisen, 1973)

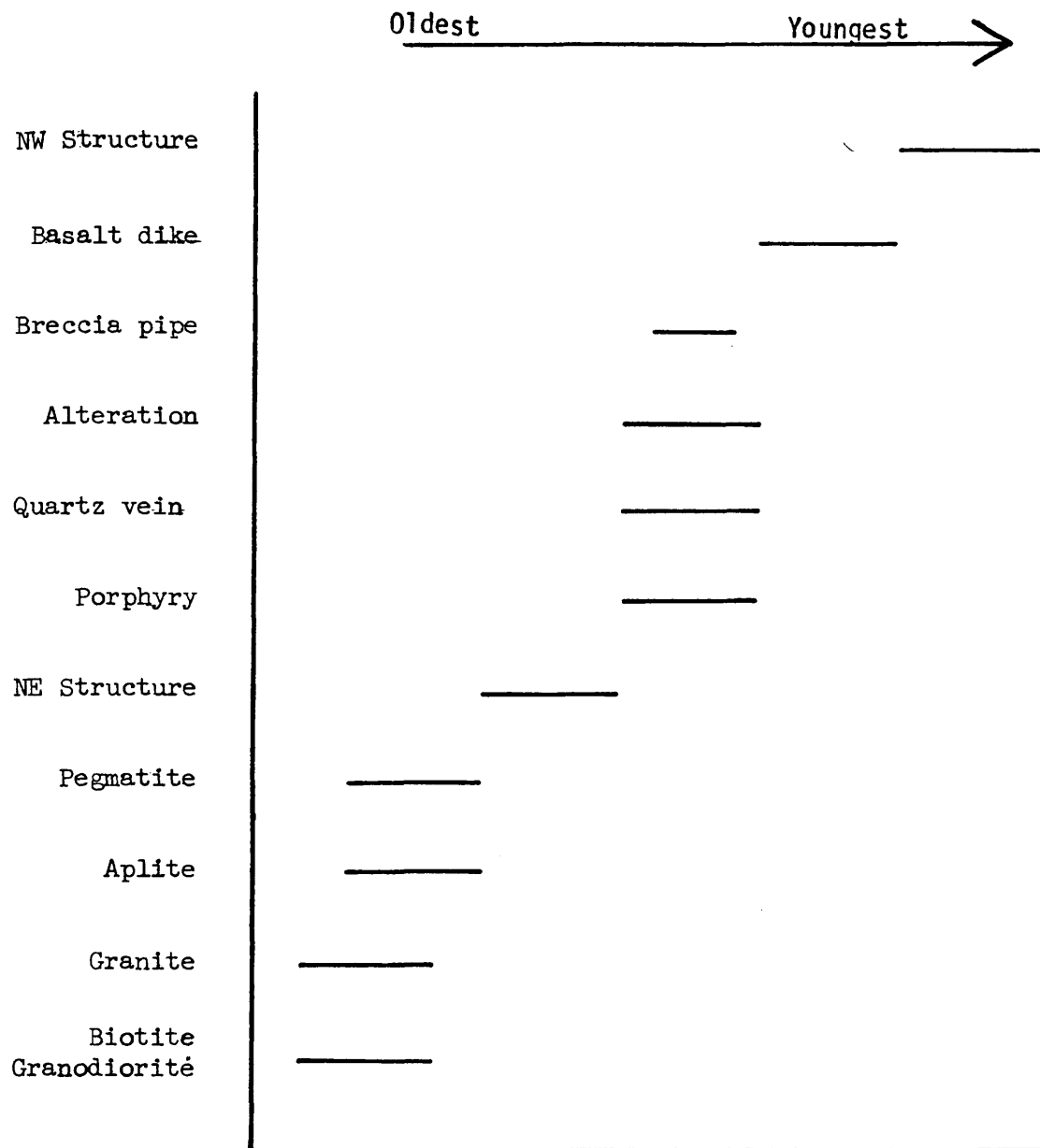


Figure- 8- Relative ages of major events.

the precision of the dates, these events are essentially contemporaneous (Fig. 8).

Because the quartz veins and hydrothermal alteration follow north-east trending joint and incipient fracture systems, those systems are older. Alteration along incipient fractures cross-cuts the granite, granodiorite, and the aplite dikes, but does not cut the quartz-feldspar porphyry. Quartz veins cut neither the aplite dikes nor the porphyry. The slight difference in ages of these events may be a satisfactory explanation as to why the quartz veins do not cut the porphyry. The lack of close proximity of the small number of quartz veins to the regions of porphyry and aplite occurrence may also explain the lack of cross-cutting relations. The lack of required joints within the porphyry is the major reason it is not cut by other features.

Despite these factors, the age dates indicate the quartz-feldspar porphyry, quartz-sericite veins, and hydrothermal alteration are related. The intrusive breccia may be approximately the same age because there is altered porphyry in the breccia sequence and unaltered porphyry along the breccia at its eastern end.

The northwesterly-trending joint system is of uncertain age. It cuts granite, granodiorite, quartz-sericite veins, and altered fractures and is therefore younger than the alteration. The basalt dikes are also of questionable age. They are cut by the late northwest trending joints, but not by any of the other features (Fig. 8). They appear to be following the northeasterly trending joint system.

Myers (1952) reports some Oligocene basaltic lavas in adjacent areas and the dikes may be related to that event. It appears that the basalt dikes and northwest-trending joints were the final events, aside from uplift, erosion and glaciation, in the study area.

### Mineralization Characteristics and Genesis

#### Quartz veins

Sulfide mineralization is confined almost entirely to steeply dipping quartz veins. The quartz veins range in thickness from 2 cm to more than a meter in width. They occur along the northeast trending joint and fault systems previously described. Most of the quartz is milky-white and massive. Other veins show comb structure, characteristic of open space filling. A vuggy zone occurs near the center of these veins with quartz crystals protruding into the open space, indicating inward growth from vein walls (Park and MacDiarmid, 1970).

Most veins have sharp contacts with wall rocks. Contacts are more irregular where hydrothermal alteration is well developed. These veins show characteristics of both fracture filling and replacement. Apparently, mineralizing solutions were introduced into fractures and during development of the resultant veins, minor replacement of the wallrock followed. Most veins pinch, swell, and are discontinuous. All are believed to be related and emplaced in the same time period.

Veins contain coarsely-crystalline flakes and rosettes of secondary muscovite, often intergrown with molybdenite. A few large masses of

secondary alkali feldspar are scattered along the inner areas of the quartz veins, with the muscovite and molybdenite.

Coarse-grained, white quartz also occurs in irregular to lenticular shaped pods and stringers, up to 7 cm across. Many of these pods contain the coarse-grained secondary muscovite flakes and rosettes. The pods occur in zones, such as the two east of Anchor Lake, that are more intensely fractured and lightly altered. Such zones form a very weak stockwork. The quartz pods occur where, at least two or more, fractures meet; quartz fills the area of intersection. Two to 3 cm blebs of pyrite, magnetite or pyrrhotite also occur at some of these intersections. Pyrite and quartz are often found together in the pods. Further to the southwest, large aggregates of crystalline epidote are found accompanying quartz. No pyrite, magnetite, or pyrrhotite were observed. A very minor trace of molybdenite occurs in one of these pods. This is the only molybdenite observed in the weak stockwork zones.

#### Primary Hydrothermal Minerals

Pyrite, molybdenite, and chalcopyrite are the principal hypogene sulfides in the quartz veins. These sulfides are generally accompanied by minor hematite and magnetite. Other primary minerals found scattered throughout the area are galena, scheelite, and pyrrhotite.

Sulfide distribution within the veins is erratic. Not all veins have been mineralized and many carry only pyrite. Sulfides may comprise up to 5 percent of a vein, but most contain less.



Molybdenite exhibits three different habits: (1) as large crystal plates and rosettes; (2) very finely disseminated throughout the quartz; and (3) as a fine-grained paint along fractures. The plates and rosettes range up to 1 cm across, with rosettes generally very well formed. They often interfinger with coarse grained hydrothermal muscovite.

The finely disseminated molybdenite is distinguished from the other fine grained minerals in the quartz only by microscopic techniques. This form of molybdenite occurs as individual, widely scattered, crescent shaped flakes. Where these disseminated flakes are abundant, the quartz takes on a gray color. Some of this color is also due to finely disseminated pyrite.

The bluish-gray paint along fractures is generally a mixture of smeared pyrite and molybdenite. This often results in a gray banding within the quartz. Microscopy shows a few of the crescent shaped plates remaining within the paint, but most grains have been destroyed along the fracture.

Chalcopyrite is observed accompanying molybdenite in only two areas. Fine grained molybdenite and coarse, anhedral chalcopyrite are intermixed in a small vein to the southeast of Tent Mountain and within veins on the flanks of Torrey Mountain. Very minor chalcopyrite occurs in the veins west of Tub Lake and west of Chan Lake (Fig. 13). Chalcopyrite also occurs along small fractures in unaltered rock to the north and south of the breccia pipe. Whether it is related to the breccia, or not, is unknown.

Galena occurs with chalcopyrite west of Chan Lake and with molybenite in the large vein on Tent Mountain. The galena in these localities is well-crystallized. Grains are sparsely scattered, ranging from microscopic to 1 cm across. Pyrite is usually closely associated with the galena.

Specular hematite is found closely intermixed with molybdenite in a few small veins, northeast of Pear Lake. These veins have been revealed by prospect pits. The fine-grained mixture of hematite and molybdenite is deceiving. It is nearly impossible to discriminate between the shiny, gray specular hematite and the molybdenite. The combination results in a characteristic red streak of hematite. Geochemical assay reports verify the presence of molybdenite (AMAX 1977, personal communication).

Grains of scheelite, up to 7 mm across, occur in the quartz veins west of Tub Lake. Fine grained blueish scheelite has been verified in several other quartz veins by use of short wave ultraviolet light. It is not abundant.

#### Hydrothermal Alteration

Hydrothermal alteration at the Birch Creek prospect is mostly confined to narrow envelopes bordering quartz veins which commonly grade outward into unaltered, or weakly altered, biotite granodiorite. A few small patches of altered rock west of Pear Lake are not associated with quartz veining. Lowell and Guilbert

(1970) call this a "dry" type of alteration, where abundance, involvement, and permeation of mineralizing-altering fluids is low.

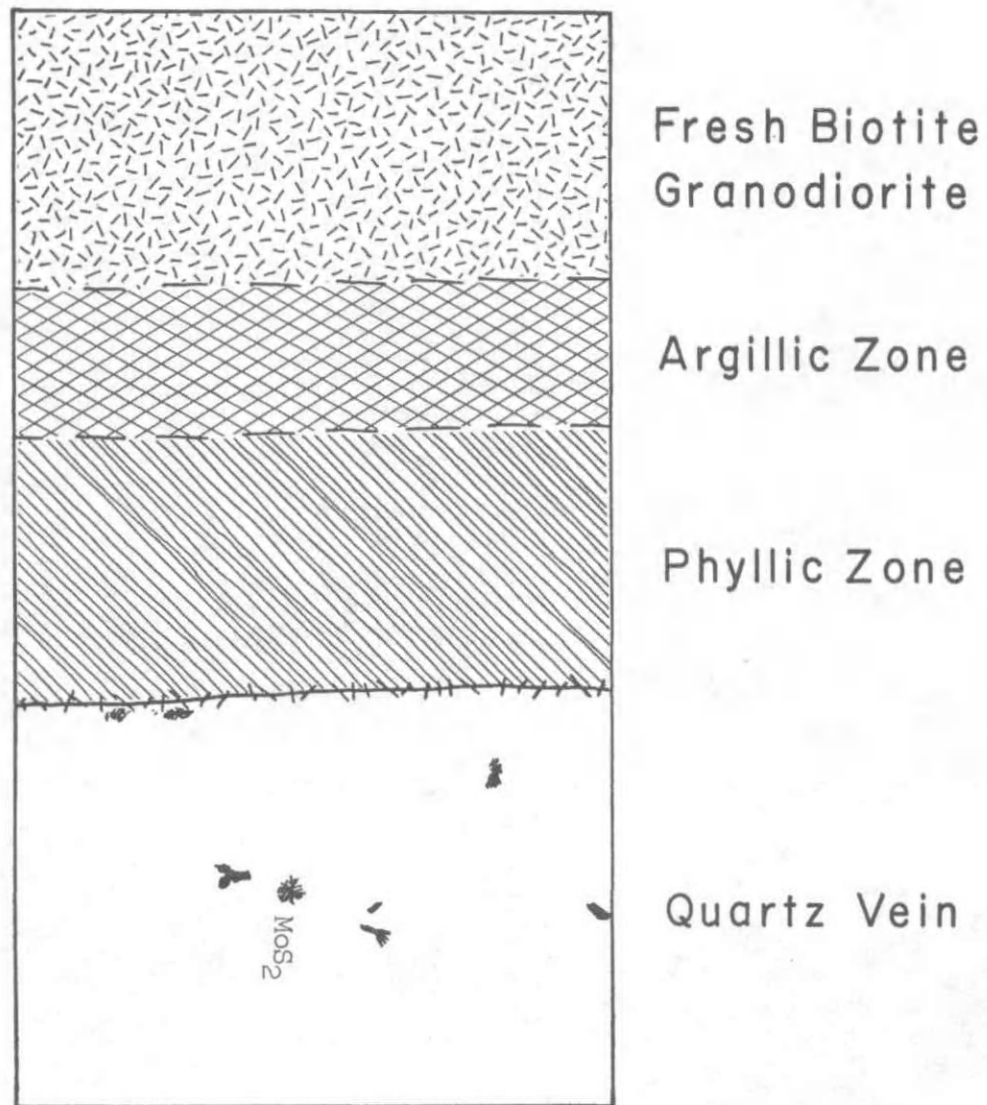
The alteration envelopes range from 4 cm to 1.5 m in width. Where veins are closely spaced, such as west of Tub Lake, alteration envelopes on adjacent veins coalesce to produce local areas of pervasive alteration. There are few of these coalescing zones in the area.

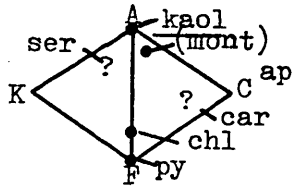
Only two types of hydrothermal alteration exist. Both are related in space and time to the quartz veins (Fig. 9). These alteration types have the characteristic mineral assemblages of the phyllic and argillic zones (Fig. 10) (Lowell and Guilbert, 1970). The idealized, inner potassic and outer propylitic zones have not been recognized in the alteration sequence.

The phyllic zone, sometimes called the sericitic zone, is the most abundant and significant of the two alteration assemblages. The alteration minerals include quartz, hydrothermal muscovite (sericite), pyrite, rutile, and minor amounts of chlorite and biotite (Plate 8). The phyllic zone is the most intensely altered to judge from extent of destruction of the original rock texture and minerals.

As noted by Burnside (1970), the term sericite is widely used to denote a specific genetic origin in hydrothermal alteration. In this case it is not necessarily limited to the fine-grained secondary habit. With this in mind, the coarse-grained, secondary white mica found in the phyllic alteration assemblage is termed hydrothermal muscovite in this study. This mineral falls in the same position as sericite in the hydrothermal

Fig. 9 Alteration zones in relation to quartz vein (to scale).



SHALLOW-MODERATE DEPTH ASSEMBLAGES	
FRESH	ARGILLIC ZONE
PORPHYRIES	
Quartz	Augmented
Orthoclase-	Flecked with Sericite
Microcline	
Plagioclase	Montmorillonite Kaolin
Biotite	Chloritized + leucoxene, qtz
Hornblende	Chloritized
Magnetite	Pyritized
A-K-C-F  A=Al K=K, Na C=Ca salts F=Fe, Mg  Outer	
Veinlet Fillings	Q-ser-py-chlor

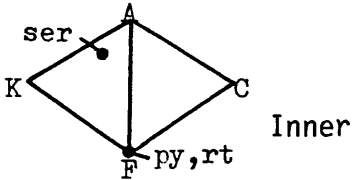
PHYLLIC ZONE
Augmented
Sericitized
Sericitized
Sericite, pyrite, rutile
Sericite, pyrite, rutile(?)
Pyritized

Q-ser-py

Figure 10 Summary of hydrothermal alteration assemblages.  
(After Lowell and Guilbert, 1970)

alteration assemblages described by Lowell and Guilbert (1970). This is also the mineral described with the quartz veins.

X-ray diffraction analysis of a clean, mono-mineralic sample of this muscovite shows the  $10 \text{ \AA}$ ,  $5 \text{ \AA}$  and  $3.3 \text{ \AA}$  lattice spacing typical of muscovite (Carrol, 1970). The sharp, well-defined diffraction peaks indicate the well-crystallized nature of the muscovite. According to Hemley and Jones (1964) this type of muscovite is generally potassium-rich, but sodium and magnesium may be present in significant amounts.

Hydrothermal muscovite may comprise up to 99 percent of the alteration minerals near the quartz vein. The majority of the phyllic alteration has between 25 and 35 percent of this muscovite. Most flakes range from microscopic dimensions to 8 mm across.

Original rock plagioclase and orthoclase are both pervasively replaced by a felted mat of coarse hydrothermal muscovite (Plate 8). In some cases original mineral textures are retained in the preferred orientation of the sericite. Sericite also occurs as coarse rosettes, often intergrown with coarse molybdenite flakes in this zone.

Quartz is usually the most abundant mineral in the phyllic zone. It may comprise up to 70 percent of the altered rock. Primary rock quartz is generally unaffected, but may show rounded overgrowths.

Pyrite is abundant in some envelopes, but for the most part it has been pseudomorphically replaced by hematite and extensively oxidized to limonite. This oxidation gives the alteration envelopes a

distinctive red-orange color. Original pyrite content was probably in the 1 to 3 percent range.

Original potassium feldspar is totally replaced by coarse grained sericite close to the vein, but small unaltered fragments remain, away from the vein. A trace of rutile is present and no carbonates were observed.

The contacts of the phyllic zone with the associated quartz vein are relatively sharp. Occasionally, coarse-grained hydrothermal muscovite and molybdenite will be intergrown across the vein-phyllic assemblage interface. This intergrowth is not dense enough to obscure the contact. The contact of the phyllic zone with the outermost argillic zone is well-defined, but gradational over about 2 cm. Minerals of the phyllic assemblage and those of the argillic assemblage overlap to some extent in the gradational area.

Argillic alteration of the biotite granodiorite is restricted to the envelopes surrounding quartz veins. The argillic assemblage is very thin in most cases. The widest of these zones is 6 to 7 cm. This is another factor suggesting the hydrothermal, metasomatic fluids were not abundant or the duration of the process was relatively short.

The characteristic alteration mineral in the argillic assemblage is kaolinite. Oriented samples give distinctive X-ray diffraction peaks of approximately  $7\text{\AA}$  and  $3.57\text{\AA}$  (Carroll, 1970) and is verified by the collapse of these peaks on heating to  $550^{\circ}\text{C}$  for one hour. It appears well-crystallized, as shown by the sharp, narrow peaks. Disordered kaolinite was detected in only one sample X-rayed. The

disordered nature was indicated by broadening of the characteristic peaks.

Argillic alteration assemblages are often internally zoned (Meyer and Hemley, 1967). Such zoning is not readily detectable in the prospect area. Zoning is represented by conversion of plagioclase to abundant kaolinite near the phyllic contact and sparse montmorillonite in the outer portion. Montmorillonite was identified in only one of the samples X-rayed. The characteristic  $15 \text{ \AA}$  peak expanded to almost  $17 \text{ \AA}$  upon glycolation and became  $9 \text{ \AA}$  when heated to  $300^{\circ}\text{C}$  for one hour.

Pyrite is less common than in the phyllic zone. It is generally oxidized to limonite. Quartz is common and is overgrown with secondary quartz. Potassium feldspar has been extensively replaced by fine-grained hydrothermal muscovite (Fig. 10). Biotite is present, but not common. It is slightly altered to chlorite along cleavage. No carbonates have been identified.

Alteration becomes weaker away from the quartz vein. The argillic zone grades, rather abruptly, into fresh biotite granodiorite over a few centimeters (Fig. 9). The argillic zone has a heavy limonite staining, that also decreases away from the vein. This stain occurs in a pattern similar to diffusion banding, with heavy reddish stain at the phyllic contact, becoming less intense toward fresh rock. This diffusion away from the phyllic zone may be the result of metasomatic fluids carrying iron outward from the phyllic zone where pyrite is being oxidized. Conversely it may be a weathering affect on higher concentrations of pyrite near the vein, becoming less outward.



Hydrothermal alteration in the areas of the weak stockwork resembles the phyllic alteration. Hydrothermal muscovite is predominantly very coarse-grained in these areas. The alteration extends only a few centimeters away from the quartz pods, with fresh biotite granodiorite between stringers and pods. South of Pear Lake, where muscovite and quartz-bearing pods are accompanied by a significant amount of epidote, the alteration vaguely resembles the propylitic assemblage.

It should be noted that the zones of weak stockwork, and some quartz veins, are at the same elevation in the prospect area. Outcrops occur between 8800 and 9000 feet in elevation. Most crop out on the eastward facing slope of a glacial bench. Whether this is purely by accident or not is subject to speculation.

North of Tub Lake are two very small zones of propylitic alteration. The mineral assemblage does not fit that of the propylitic zone, as described by Lowell and Guilbert (1970), but is closer to that assemblage than the others. Propylitic alteration assemblages may vary according to host rock composition. The alteration occurs along small fractures and grades outward into fresh wall rock. Epidote is the dominant mineral, ranging up to 95 percent of the rock. The remainder of the alteration assemblage is composed of chlorite, quartz, hematite, and rutile. There are no associated quartz veins.

Two slightly irregular alteration zones near Chan Lake do not clearly fit one of the alteration assemblages. They are composed predominantly of sericite and iron oxides, with abundant quartz. The major difference is the high carbonate content. Calcite is a primary

hydrothermal alteration mineral, makes up 15 to 20 percent of the altered rock.

Hydrothermal alteration minerals also occur along the altered fractures (Plate 1). From the flanks of Torrey Mountain, to the Boot Lake area, these fractures carry pyrite, sericite, quartz, or a combination of any or all of these. In the Anchor Lake area and north of Pear Lake the fractures are predominantly pyrite and/or sericite filled. Near Tub Lake and further to the south, the fractures carry pyrite only. West of Pear Lake, around Chan Lake and the breccia zone, the fractures carry smeared epidote and magnetite. Pyrite in these fractures is highly oxidized near the surface. In thin section it is observed in close proximity to biotite, suggesting iron may have been drawn from the biotite to form pyrite.

This northeast-trending zone of altered incipient fractures can be traced from Torrey Mountain to Tent Mountain, disappearing under cover in the south. The fracture controlled alteration does not occur in the high ridges to the extreme west, east, or north.

### Secondary Minerals

Secondary minerals are not well-developed in the prospect area. Chalcocite and covellite appear in small amounts in polished sections from quartz veins northwest of Chan Lake. Covellite is most abundant of the two. It occurs in close association with pyrite and also intergrown with and surrounding galena. The chalcocite probably occurs at the expense of chalcopyrite, and covellite at the expense of chalcocite. These secondary minerals have an irregular form and spongy texture due

to weathering. The chalcopyrite-pyrite-chalcocite-covellite assemblage is not in equilibrium (Taylor and Kullerud, 1969).

### Oxidation

Oxidation minerals in the Birch Creek prospect area are apparent from their yellow to brown surface coating on quartz veins and alteration envelopes. Oxidation of pyrite to iron oxide products is quite extensive at the surface. Fresh pyrite exists only in the interiors of massive quartz veins.

The major oxidation product is soft, earth-brown, goethite. The goethite is derived from the disseminated sulfides and precipitated as indigenous, fringing, and exotic products (Blanchard, 1968). Goethite also occurs as a crusty coating on the surfaces of joints and fractures. Wilson (1965) states that a higher luster goethite, containing up to 7 percent molybdenum, has been reported in some molybdenite deposits.

Another common oxidation product is hematite. Most grains are soft and red. High luster specular hematite is common east of Pear Lake. Specular hematite is a common hypogene mineral with unknown significance (Giles and Thompson, 1972).

Jarosite occurs in intimate mixtures with goethite and hematite. It is a light yellow to yellowish green mineral, forming a thin coating on most quartz veins. Sub-equal amounts of resinous pitch-limonite also occur in the large oxidation zones.

Massive and fibrous malachite occurs as coatings on quartz veins where chalcopyrite and secondary copper minerals occur. It also occurs sprinkled through the carbonate bearing alteration zones. Malachite

and a minor amount of zurite have developed, to a greater extent, in the small chalcopyrite-bearing quartz veins on Tent Mountain.

Ferrimolybdate forms abundant coatings along fractures in molybdenite-bearing veins. The mineral occurs as a fine-grained, canary yellow to straw yellow, earthy, oxidation product. Individual grains are microscopic, often accumulating to form thin crusts. The abundance and ubiquitous distribution of the ferrimolybdate is somewhat surprising, considering the sparse scattering of molybdenite and the fact that, according to Blanchard (1968), molybdenite does not oxidize readily.

Generally, molybdenite and pyrite coexist where oxidation has not occurred. According to Carpenter (1968), ferrimolybdate occurs below the surface in low pH environments. Molybdenite and pyrite occur in even lower pH environments, below the water table. Apparently, ferrimolybdate is most stable at a pH of 3.2, dissolving at a lower pH and decomposing in alkaline environments (Fig. 11). As a result, molybdenum is leached from veins where the pH is between 1.0 to 1.5 and precipitated in fractures where pH varies from 1.5 to 3.2. Oxidation may take place up to a pH of 6.2. Carpenter (1968) states the acid molybdate iron and excess ferric iron from oxidation of pyrite and molybdenite, combine to form ferrimolybdate. This reasoning would seem to explain the highly oxidized nature of the molybdenite.

Oxidation of sulfides is very intense in some cases. In several areas quartz has been converted to what Blanchard (1968) refers to as cellular sponge. The sponge is composed of a mixture of silica and limonite. A fluctuation of Eh and pH conditions between acid and

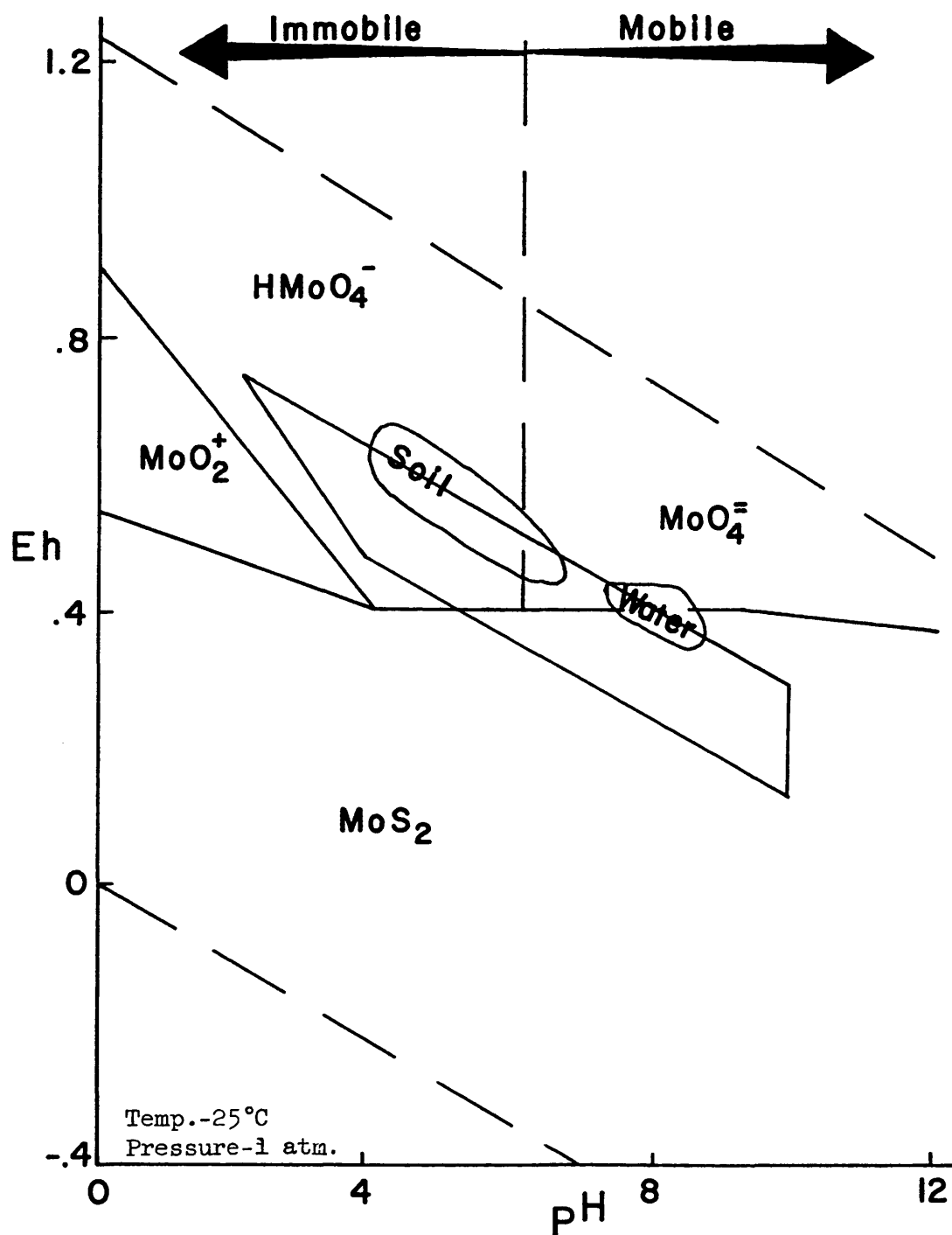


Figure-11-Stability relations in molybdenum-water system.  
(After Hansuld, 1966)

alkaline is required to produce such a sponge, since sulfides are oxidized under acid conditions (Fig. 13) and silica (quartz) is soluble in alkaline conditions (Krauskopf, 1967). Blanchard (1968) explains this through fluctuating groundwater levels. Below the water table, groundwater tends to be alkaline, thus, dissolving silica. Descending acid solutions, carrying iron, are neutralized by the alkaline solution and goethite is precipitated. As the water table drops, conditions become more acidic, with increased oxidation of sulfides, and the silica is reprecipitated. The result is a cellular sponge of silica and limonite. The process is a slow one and is greatly dependent on annual precipitation and water table fluctuations. Completion of this process is rare, which is why massive quartz remains in most cases. This process may also be affected by the fact that pyrite may oxidize under alkaline conditions also (Fig. 13).

#### Mineral Zoning

Mineral zoning is evident in the prospect area. The most evident zoning exists in the northeast trending altered incipient fracture network. From Torrey Mountain to Boot Lake, any combination of quartz, sericite, or pyrite occupy the fractures. In the Anchor and Pear Lake areas the fractures are predominantly pyrite and/or sericite filled. In the Tub Lake area, and farther to the south, the fractures are almost totally filled with pyrite. To the west of Pear Lake, epidote and magnetite occur in the fractures. Epidote is also common south of Pear Lake, with some pyrite. A progression of hydrothermal minerals is represented in this northeast trending zone (Fig. 14).

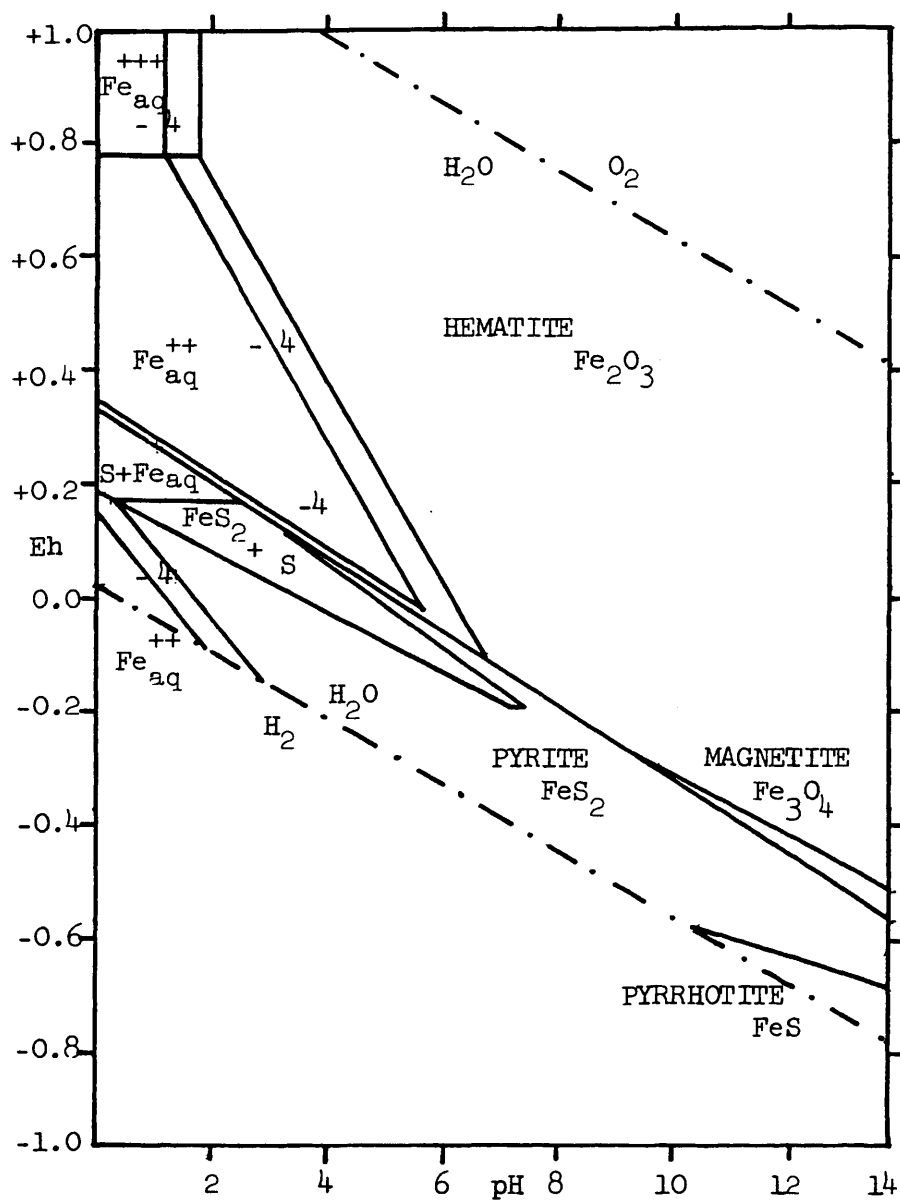


Figure-13- Stability relations of iron oxides and sulfides in water at 25°C and 1 atm. total pressure-activity of dissolved sulfur  $10^{-1}$  (After Garrels and Christ, 1965).

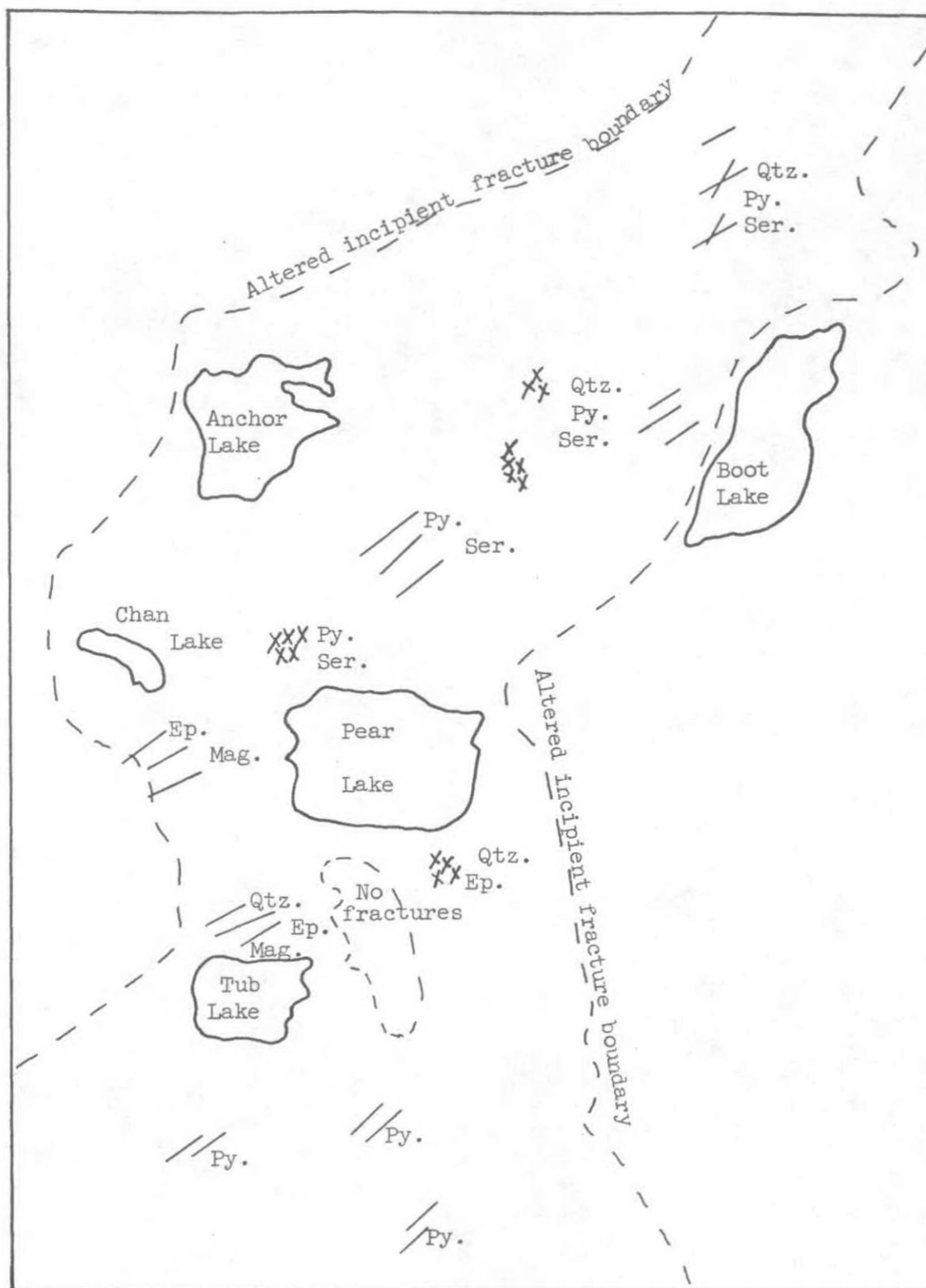


Figure-14 Alteration zoning in incipient fractures.



Metallic mineral zoning is not as evident. Molybdenite mineralization, with no accompanying metallic minerals, is confined to the interior of the cirque floor (Fig. 15). Copper and lead mineralization, with minor molybdenite, is confined to the quartz veins on the walls of the cirque. This zoning roughly follows the sequence of metal transport in hydrothermal solutions proposed by Barnes (1962) and Barnes and Czmanske (1967). In that sequence, molybdenum (in approximately the same position as tin) precipitates early in the mineralization process. This precipitation occurs because of the unstable nature of the molybdenum complex in the transporting medium. Copper and lead are more stable in the transporting fluid. Therefore, they are carried farther before being precipitated. Thus, molybdenite occurs in the center of the cirque and copper-lead in the outer walls assuming an outward flow.

According to Carpenter (1968) and Soregaroli (1968), the molybdenite may be accompanied by magnetite and the alteration mineral assemblages. Pyrite and other sulfides may be deposited contemporaneously, with the copper and lead minerals later. Quartz is the earliest gangue mineral. It is associated with the early molybdenite and alteration assemblages, although it may occur throughout the mineralizing sequence.

Molybdenum mineralization may occur near the central part of the mineralized area because of its high affinity for sulfur (Enzmann, 1972). During precipitation of hydrothermal minerals, other sulfides will form only after all molybdenum has combined with sulfur to form molybdenite.

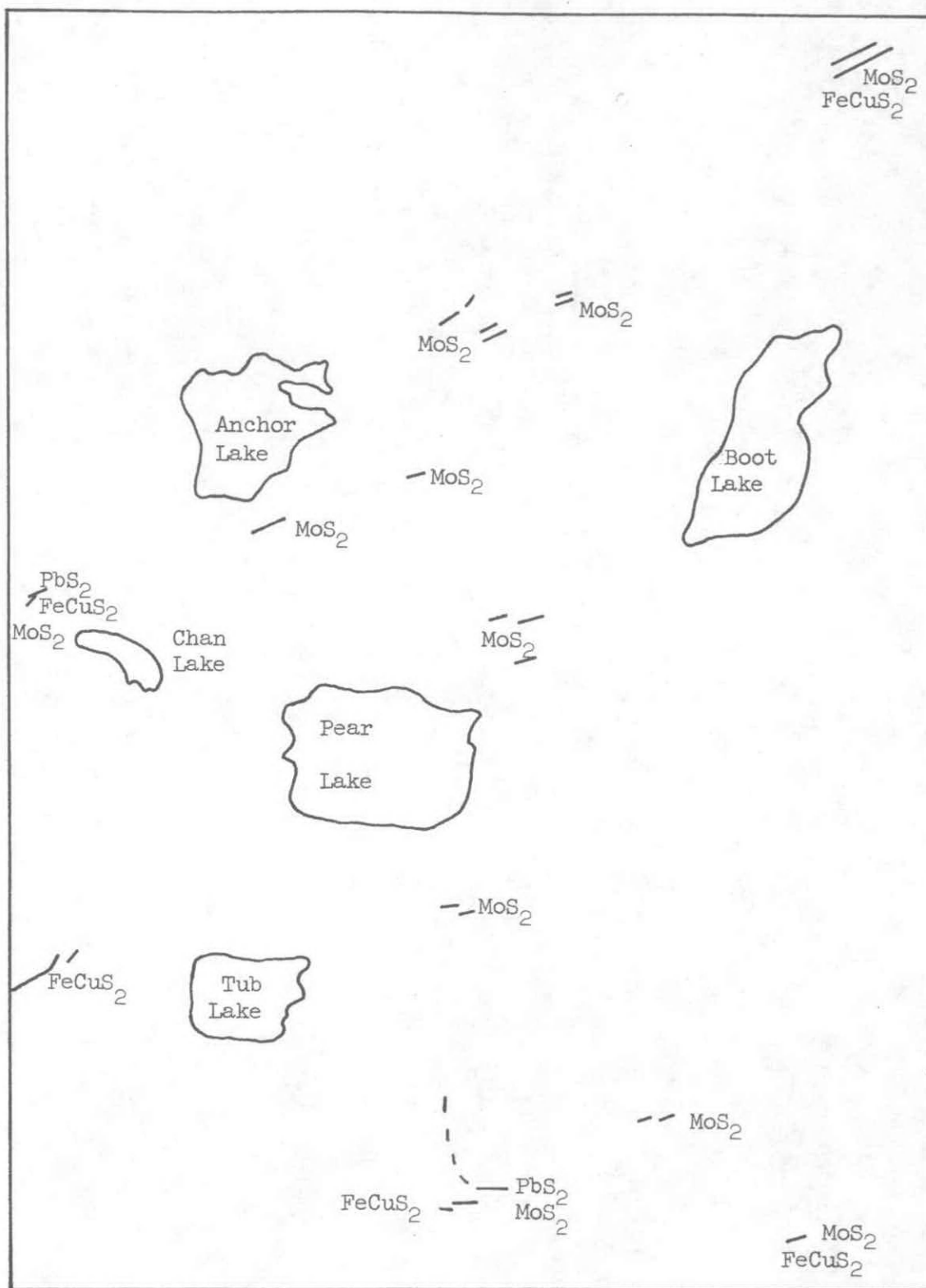


Figure-15-Mineral zoning.

A vertical zoning also occurs as a result of these factors. Copper and lead minerals occur in the higher elevations relative to molybdenite. Probably the most important factor limiting vertical and horizontal zonation of minerals in the Birch Creek prospect is the regional structural fabric.

### Discussion

The processes that form the type of hypogene mineralization and hydrothermal alteration at the Birch Creek deposit are believed to have occurred at temperatures around 350 to 500<sup>0</sup>C. According to Drummond and Kimura (1969), the lack of a propylitic alteration assemblage suggests maximum temperatures were less than 350<sup>0</sup>C. Roy and Osborne (1954) state that the predominance of kaolinite, such as that found in the argillic envelope, suggests a temperature of formation below 400<sup>0</sup>C, which tends to support the statement by Drummond and Kimura.

The availability of an extensive aqueous phase for transport of minerals and metasomatism may also have been a limiting factor at Birch Creek. Without a volumetrically adequate aqueous phase, from the intrusive or some circulation of meteoric waters, neither concentration nor transport of metals and hydrothermal minerals can occur (Burnham, 1967; Sheppard et al., 1971; Holland, 1972). Apparently, without the proper conditions of temperature and pressure during hydrogen metasomatism, neither alteration nor mineralization can proceed to economically interesting levels.

Molybdenite, pyrite, copper and lead sulfides and oxides probably accompanied the late, silica rich, aqueous phase that was localized along fractures and pockets of weak stockwork. According to Giles and Thompson (1972), the low molybdenite content in the mineral assemblage suggests a moderate to low amount of molybdenum available to the solutions from the source melt. The fairly high percentage of pyrite in comparison to other sulfides in the prospect area should, therefore, suggest a system with excess sulfur and iron.

It would appear that the varied and highly localized nature of the hydrothermal alteration and quartz veins may be a result of a poorly-fractionated hydrothermal system, with limited circulation. Perhaps hydrothermal process had little or no time to operate and concentrate the molybdenite effectively. This may be the most important reason for the small quantity of molybdenite in the mineralized areas. The primary, steeply dipping, northeast trending joint system served as the localizing control for the hydrothermal fluids and subsequent mineral deposition that occurred.

In this study it has not been possible to draw a clear distinction between Pioneer magmatism and a slightly later episode of molybdenum mineralization and alteration that affected the biotite granodiorite. The field, mineralogical, and age relationships show that mineralization occurs largely within the framework of late Pioneer magmatic activity and cooling.

Age relationships between the quartz-feldspar porphyry, hydrothermal mineral assemblages, and quartz veins justify a certain amount of speculation regarding their association. There is a strong possibility the intrusive breccia is also closely related. Gilmour (1977) insists such an intrusive breccia indicates the existence of a buried intrusion. If the quartz-feldspar porphyry is another expression of that buried intrusion, then age relationships may indicate the mineralization is related to the porphyry rather than the biotite granodiorite. Lack of mineralization associated with the porphyry is a major problem with this theory.

Many intrusive breccia pipes have economic mineralization associated with them. The nature of single breccia pipes has been studied (Wallace et al., 1968a; Wallace et al., 1968b; White and MacKenzie, 1973; and Soregaroli, 1975) and as a result they are actively sought as possible guides to commercial molybdenum deposits.

Bryner (1961) has divided intrusive breccias into two groups, prehydrothermal and cohydrothermal. He states that a great proportion of the cohydrothermal pipes are likely to be mineralized. From the relationships observed, it would appear that the Birch Creek breccia is of the cohydrothermal variety. On the basis of Bryner's statement, this breccia pipe would have a better chance of being mineralized than a prehydrothermal one. That mineralization, if it exists, is beneath the surface.

Kents (1961) suggests another reason for the lack of appreciable mineralization related to the formation of the intrusive breccia. He suggests that within a semi-closed system, nearly all the sulfides may be expected to precipitate within that system. In an open system, the rising fluids may escape. As a result, sulfides do not precipitate in either the intrusion or the breccia sequence. In this case the buried intrusion may have vented, losing its mineralizing fluids through the intrusive breccia. Perhaps the mineral-bearing quartz veins were deposited before venting, as pressure was building. Conversely quartz veins may have been precipitated after the venting, when the pipe was resealed, remaining fluids moving upward along joints as a result of renewed pressures. These speculations depend upon a buried intrusion or at least a phase of the biotite granodiorite in the latest stages of crystallization.

The simplest explanation for the mineralization is that it is a result of late-stage poorly fractionated fluids related to the biotite granodiorite. The reasons for sparse molybdenite mineralization in this case have already been proposed. Perhaps glacial activity has uncovered only the top of that mineralization. Many economic mineral deposits have been discovered where only a few quartz veins crop out at the surface. Lowell and Guilbert (1970) have concluded that large quartz veins are commonly structurally high in the hydrothermally altered body of rock. Another possibility is that the glacial activity has uncovered the only mineralization in the prospect area.

The reason for the belt of hydrothermal alteration zones and quartz veins, between 8800 and 9000 feet, is unknown. The fact that this belt lies along the face of one of the glacially carved benches may be significant. This bench may represent a structurally weak area that allowed movement of hydrothermal fluids and was later susceptible to glacial action. Perhaps the level of erosion is favorable for observation of the hydrothermal alteration. It should be noted that many of the quartz-feldspar porphyry masses outcrop at this level, or at least close to it, increasing the possibility of a structurally weak zone.

## BIBLIOGRAPHY

- Alden, W.C., 1953, Physiography and glacial geology of western Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 231, 200 p.
- Armstrong, R.L., Hollister, V.F., and Harakal, J.E., 1978, K-Ar dates for mineralization in the White Cloud-Cannivan porphyry molybdenum belt of Idaho and Montana, *Econ. Geol.* v. 73, p. 94-108.
- Balk, R., 1937, Structural behavior of igneous rocks: *Geol. Soc. America Mem.* 5, 177 p.
- Barnes, H.L., and Czamanske, G.K., 1967, Solubilities and transport of ore minerals, in Barnes, H.L., ed. *Geochemistry of Hydrothermal Ore Deposits*: Holt, Rinehart, and Winston, New York, p. 334-378.
- Billings, M.P., 1972, *Structural Geology*: Prentice-Hall, Inc., New Jersey, 606 p.
- Blanchard, R., 1968, Interpretation of leached outcrops: *Nevada Bur. Mines Bull.* 66, 196 p.
- Bryant, D.G., Intrusive breccia associated with ore, Warren, (Brisbee) mining district, Arizona: *Econ. Geol.*, v. 63, p. 1-12.
- Bryner, L., 1961, Breccia and pebble columns associated with epigenetic ore deposits: *Econ. Geol.* v. 56, p. 488-508.
- Burcham, C.W., 1967, Hydrothermal fluids at the magmatic stage, in Barnes, H.L., ed., *Geochemistry of Hydrothermal Ore Deposits*: Holt, Rinehart, and Winston, New York, p. 34-76.
- Burnside, M., 1970, Alteration petrology in the Potosi mining district, Tobacco Root Mountains, Montana: Unpublished Masters thesis, University of Montana, 70 p.
- Carpenter, R.H., 1968, Geology and ore deposits of the Questa molybdenum mine area, Taos County, New Mexico, in Ridge, J.D., ed., *Ore Deposits of the United States, 1933-1967* (Graton-Sales Vol. 1 & 2): Am. Inst. Mining Metall. Petroleum Engineers, New York, p. 1328-1350.
- Carroll, D., 1970, *Clay Minerals: A guide to their X-ray identification*: *Geol. Soc. America Special Paper* 126, 80 p.



- Drummond, A.D., and Kimura, E.T., 1969, Hydrothermal alteration At Endako - a comparison to experimental studies: Canadian Mining Metall. Bull., v. 62, p. 707-714.
- Enzmann, R.D., 1972, Molybdenum: Elements and geochemistry, in Fairbridge, R.W., ed., The Encyclopedia of Geochemistry and Environmental Sciences: Van Nostrand Reinhold, New York, p. 753, 758.
- Garrels, R.M., and Christ, C.L., 1965, Solutions, Minerals, and Equilibria: Harper & Row, New York, 450 p.
- Gates, O., 1959, Breccia pipes in the Shoshone Range, Nevada: Econ. Geol., v. 54, p. 790-815.
- Geach, R.D., 1972, Mines and mineral deposits (except fuels), Beaverhead County, Montana: Montana Bur. Mines Geol. Bull., 85, 194 p.
- Giles, D.L., and Thompson, T.B., 1972, Petrology and mineralization of a molybdenum-bearing alkali stock; Sierra Blanca; New Mexico: Geol. Soc. America Bull., v. 83, p. 2129-2148.
- Gilmour, P., 1977, Mineralized intrusive breccias as guides to concealed porphyry copper systems: Econ. Geol., v. 72, p. 290-303.
- Hemley, J.J., and Jones, W.R., 1964, Chemical aspects of hydrothermal alteration with emphasis on hydrogen metasomatism: Econ. Geol., v. 59, p. 538-569.
- Holland, H.D., 1972, Granites, solutions, and base metal deposits: Econ. Geol. v. 67, p. 287-301.
- Hibbard, M.J., 1965, Origin of some alkali feldspar phenocrysts and their bearing on petrogenesis: Am. Jour. Sci., v. 263, p. 245-261.
- Hyndman, D.W., 1968, Petrology and structure of Nakusp map area, British Columbia: Geol. Survey Can. Bull., v. 161, 95 p.
- \_\_\_\_\_, 1972, Petrology of Igneous and Metamorphic Rocks: McGraw-Hill Book Co., New York, 533 p.
- Johnston, W.P., and Lowell, J.D., 1961, Geology and origin of mineralized breccia pipes in Copper Basin, Arizona: Econ. Geol. v. 56, p. 916-940.

- Karlstrom, T.N.V., 1948, Geology and ore deposits of the Hecla mining district, Beaverhead County, Montana: Montana Bur. Mines and Geol. Mem. 10, 45 p.
- Kents, P., 1961, Brief outline of a possible origin of copper porphyry breccias: Econ. Geol., v. 56, p. 1465-1469.
- Kirkemo, H., Anderson, C.A., Creasey, S.C., 1965, Investigations of molybdenum deposits in the conterminous United States, 1942-1960: U.S. Geol. Survey Bull. 1183E, 80 p.
- Krauskopf, K.B., 1967, Introduction to Geochemistry: McGraw-Hill Book Co., New York, 721 p.
- Lowell, J.D., and Guilbert, J.M., 1970, Lateral and vertical alteration mineralization zoning in porphyry ore deposits: Econ. Geol., v. 65, p. 373-408.
- Meyer, C., and Hemley, J.J., 1967, Wall rock alteration, in Barnes, H.L., ed. Geochemistry of Hydrothermal Ore Deposits: Holt, Rinehart, and Winston, New York, p. 166-235.
- Meyers, W.D., 1952, Geology and mineral deposits of the northwest 1/4 Willis quadrangle and adjacent Brown's Lake area, Beaverhead County, Montana, U.S. Geol. Survey Open-file Rept. 147, 46 p.
- Park, C.F., and MacDiarmid, 1970, Ore Deposits: W. H. Freeman and Co., San Francisco, 522 p.
- Pattee, E.C., 1960, Tungsten resources of Montana: Deposits of the Mount Torrey batholith, Beaverhead County: U.S. Bur. Mines Rept. of Inv. 5552, 41 p.
- Perry, V.D., 1961, The significance of mineralized breccia pipes: Mining Eng. v. 13, p. 367-376.
- Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955, Geologic map of Montana: U.S. Geol. Survey Map.
- Roy, R., and Osborne, E.F., 1954, The system  $Al_2O_3-SiO_2-H_2O$ : Am. Mineralogist, v. 39, p. 853-885.
- Ruppel, E.T., 1975, Precambrian and lower Ordovician rocks in east-central Idaho: U.S. Geol. Survey Prof. Paper 859, chapter A, 23 p.
- \_\_\_\_\_, 1976, Medicine Lodge thrust system, east-central Idaho and southwest Montana: U.S. Geol. Survey open-file Rept. 76-366, 75 p.

- Shenon, P.J., 1931, Geology and ore deposits of Bannack and Argenta, Montana: Montana Bur. Mines and Geol. Bull. 6, 77 p.
- Sheppard, S.M.F., Nielsen, R.L., and Taylor, H.P., Jr., 1971, Hydrogen and oxygen isotope ratios in minerals from porphyry copper deposits: Econ. Geol., v. 66, p. 515-542.
- Soregaroli, A.E., 1968, Geology of the Boss Mountain mine, British Columbia: Doctoral dissertation, Univ. British Columbia, 199 p.
- \_\_\_\_\_, 1975, Geology and genesis of the Boss Mtn. molybdenum deposit, B.C.: Econ. Geol. v. 70, p. 4-14.
- Streckeisen, A.L., 1973, Plutonic rocks; Classification and nomenclature recommended by the IUGS Subcommittee on the Systematics of Igneous Rocks: Geotimes, v. 18, p. 26-30.
- Taylor, L.A., and Kullerud, G., 1969-70, Studies of sulfides, in Carnegie Institute of Washington Year Book 69, p. 315-318.
- Wallace, S.R., MacKenzie, W.B., and Blair, R.G., 1968a, Preliminary report on the geology of the molybdenite deposits at Red Mountain, Daly mining district, Colorado (abs): Econ. Geol., v. 63, p. 87-88.
- Muncaster, N.K., Jonson, D.C., MacKenzie, W.B., Bookstrom, A.A., Surface, V.E., 1968b, Multiple intrusion and mineralization at Climax, Colorado, in Ridge, J.D. ed., Ore Deposits in the United States, 1933-1967 (Graton-Sales v. 1 & 2): Am. Inst. Mining Metall. Petroleum Engineers, New York, p. 605-640.
- Waterhouse, J.H., 1952, Montana's Beaverhead tungsten: Mining World, v. 14, p. 36-39, 94.
- White, W.H., and MacKenzie, W.B., 1973, Hydrothermal alteration associated with the Henderson molybdenite deposit (abs): Econ. Geol., v. 68, p. 142.
- Wilson, J.C., 1965, Use of alteration, capping appraisal, and rock geochemistry in exploration: Unpublished field manual, 50 p.
- Winchell, A.N., 1914, Mining districts of the Dillon quadrangle, Montana: U.S. Geol. Survey Bull. 574, 191 p.
- Zen, E-An, Marvin, R.F., and Mehnert, H.H., 1975, Preliminary petrographic, chemical, and age data on some intrusive and associated contact metamorphic rocks, Pioneer Mountains, southwestern Montana: Geol. Soc. American Bull., v. 86, p. 367-370.